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WHEAT IN CANADIAN AGRICULTURE[1]

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A recent contribution to a series of articles on the wheat situation in Canada appearing in the *Financial Times* contained part of this material. The part previously published was responsible for the more elaborate report presented before the Royal Grain Enquiry Commission and here included. Earlier discussions in the series though discussing the wheat situation from various angles have not endeavoured to define the importance of wheat in the agriculture of the country. Hence this title. Obviously any attempt to fit the wheat situation into the general picture of agriculture must be somewhat sketchy on account of the brevity required. Yet at this stage some such endeavour appears well worth while.

There is, of course, no insinuation here that previous discussions have entirely neglected to stress the importance of wheat in the agriculture of the country. The probability is that it has been over-stressed. Over-stressing the importance of wheat, over-expansion of wheat growing in relation to other crops, and as well the "wheat complex" that has prevailed in this country during the post-war decade, have all helped to throw the agriculture of the country out of balance. Happily there is evidence, as we shall later see that a more reasonable balance to agriculture has been brought about during the last half decade.

DEMAND

The most important factor in the wheat situation is the probable future demand. A recent study (June 1936) by the Food Research Institute of Stanford University on Wheat Utilization since 1885 furnishes some valuable information on this point.

From 1885 to 1913 per capita consumption of wheat (ex Russia) increased by six-tenths of a bushel per annum. By 1935 it was over one-third of a bushel less per annum than in 1913. The decline in per capita utilization was attributed to consumption of less farinaceous foods with the rising standard of living and the slower rate of increase in total use attributed to the slower rate of increase in population. During the period of low prices, considerable increase occurred in the use of wheat for feed for live stock. The statement is made that wheat growers cannot reasonably expect to expand wheat acreage in the next decade and at the same time avoid accumulation of surplus stocks and a low level of price.

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It is frequently claimed that it is impossible to produce a surplus of wheat. The argument is that no matter how much is produced it will all be used. Those belonging to this school of thought consistently oppose, in season and out of season, any endeavour to reduce supply locally. One of the stock arguments is that if the local production is reduced, then Argentina or Australia will simply expand area and take up the slack. This latter claim is exactly what would happen. But not if there is no possibility of providing a surplus. If there can be no such thing as a surplus of wheat in the world, as some argue, then, what difference does it make what amount other countries produce?

What we suppose is the meaning of this argument is that there is no possibility of producing too much wheat in Canada. The question would be clearer if the concession were made that there is only a limited amount of wheat required in international trade at the moment or in prospect, and the question of moment is what share of this trade it is proposed to secure. It might be expected that we could by this time agree upon this point. Such, however, does not appear to be the case.

The specialists in the study of the wheat situation have presented many arguments in support of two different dangers. One is the fear or danger of producing too much wheat. The other is the fear or danger of not producing enough.

There is nothing new or strange about such an argument. This identical controversy has been carried on now for a number of years. This argument is by no means limited to wheat, as many other farm products have lived through the same experience and in none of them has the final word yet been uttered.

One limiting factor to the plausible presentation of these two conflicting ideas in regard to the wheat situation is that it does not get us very far, as it furnishes a poor foundation for a working policy in regard to the future. Notwithstanding the opposing views which have been kept before the public so persistently, there has developed some degree of unanimity of opinion on some points that are now influencing public policy in regard to wheat growing in this country.

PRICE AND SUPPLY

What is the use or need of worrying whether this, or any other country for that matter, should produce either too much or not enough wheat? The price forthcoming should, if not interfered with, settle that. It is the special business of price to bring forth the required supply. If and when the supply is such as to cause what is termed a "situation", or "crisis", or an "emergency", and all these terms have been used in regard to wheat in various parts of the world in recent years, then there are two possible reasons for this development; either price has failed to work automatically to regulate supply, or price has not been allowed to function freely and the interference with price previously referred to has come into play with varying results according to the type of the interference adopted.

All are aware of the numerous arbitrary interferences with the price of wheat during recent years in various countries of the world. It is necessary here to note that, if all are as thoroughly aware of the arbitrary interference with price in other goods, some of them conveniently forget this

when recommending a laissez-faire policy in regard to wheat and other farm products. With the trend toward regulation of wages in industry in this country, with the stability of prices of manufactured goods and the costs of distribution of goods in general including farm products in this country, with the regulation of prices of farm products in other countries and the quota restrictions of many countries that are important markets for surplus farm products, the advocates of a let-alone policy for agriculture appear to have a difficult position to defend.

If a freely competitive policy were allowed in all branches of industry and a free flow of labour, capital, and goods allowed from industry to industry, as well as from country to country, the let-alone policy would be logical. Such a situation never has prevailed, and the world has recently moved so far in the opposite direction, whether rightly or wrongly, that it appears necessary for Canada to fall into step.

Since 1930 there has been much less regulation in Canada of the prices of farm products than in some other countries. If the opponents of all interference with prices were right, then we should be much better off locally than in these other countries. The evidence does not support this claim. Allowing farm prices to fall so far out of line with the prices of other goods as occurred from 1930 to 1936 was unnecessary, unwise, and ineffective. Unnecessary, as some other countries did not allow this to occur even though to prevent it they had to interfere by arbitrary regulations. Unwise, in that there has developed in the wheat growing region of this country a condition which ten years of prosperous times will not overcome. (And here we do not refer to the drought areas: reference is more definite toward Alberta, where crops have not been a failure. Reginald McKenna in a recent visit said what Alberta needs is harvests. He was only partly right. Alberta has not suffered from crop failures during the past eight years. What Alberta has suffered from particularly is low prices of farm products.) Ineffective, in that the depression was felt particularly by the agricultural industry, where wages dropped to 50% of the pre-depression level and have not come back as promptly as have wages in other industries.

This is all water under the bridge now; yet it will be unwise to forget all about this experience when discussing future policy, and particularly for the reason that in 1929 the wheat growing areas had just enjoyed half a decade of good crops and high prices and were in comparatively good shape to meet adversity. The period of low prices lasted so long that the value of the agricultural plant declined tremendously. With declining values of farms, debts increased, private credit was largely replaced by public funds and thus the way paved for an increase in public assistance and regulation.

The long period of low prices of wheat from 1930–1936 was partly due to the increased supply brought about by the increase in area induced by the high prices prevailing from 1925–1929. The adjoining figures may make this clear.

WHEAT AREA CANADA, ARGENTINE, AUSTRALIA COMBINED

	Millions of acres
Av. 1910–13	33
Av. 1924–30	53
1930	63
1931	57
1932	63
1933	61
1934	55
1935	48
1936	55

Price resulted in expanding acreage in the three leading exporting countries from 1924 to 1930. From 1930 to 1935 price resulted in reducing acreage in these countries from 63 to 48 million acres, a reduction of 15 million acres, or almost one-quarter. Just what happened in Western Canada during this time will be examined in more detail. A result such as this indicates that price has some regulating effect on supply in these three leading exporting countries. This is by no means to suggest that the recent dry seasons have not also had effect upon price. It is to suggest very emphatically, however, that the price of wheat has a very salutary effect on the supply forthcoming. Not only has the price of wheat an effect upon the supply but also the price of other farm products which the wheat grower may resort to when compelled to do so. This brings up another phase of the situation which must be examined.

ALTERNATIVE OPPORTUNITIES

It has often been asserted that when wheat prices decline all farm products suffer as well. They do as a rule. But by no means regularly or to the same amount. For this reason it is ridiculous to treat wheat altogether apart from other farm products.

The farm price of wheat in Canada for the five years from 1930–1934 was 45.5 per cent of the previous five-year level. For the same period the price of potatoes was 44.4 per cent of the earlier period. This was the only staple farm crop that declined more than wheat during this period. Other declines are given: barley to 50.9, oats to 51.0, sheep and lambs to 54.8, eggs to 58.6, butter to 59.6, hogs to 61.3, calves to 61.9, beef cattle to 67.3, and sugar beets to 80.4 per cent of the earlier level.

During this period the price of grains declined to about half the level of the previous five years, butter and eggs by slightly over forty per cent, hogs and calves almost the same, while beef cattle brought over two-thirds the price of the earlier period. It was to be expected that with this difference in price some shifting would occur in farm production. It is now possible by the use of the census figures for 1936 to measure the extent of the shift during the last half decade as well as to compare it with earlier periods for the Prairie Provinces.

Wheat Area of Prairie Provinces

Millions of acres

Wheat area, census years		Farm price, 5 yr. av.	Expansion in wheat area
1911	10		
1916	14	1911–1916 76¢ per bu.	+4
1921	19	1916–1921 183¢ per bu.	+5
1926	22	1921–1926 95¢ per bu.	+3
1931	26	1926–1931 88¢ per bu.	+4
1936	25	1931–1936 48¢ per bu.	−1

During the period from 1931 to 1936 the area devoted to wheat in the three provinces declined by 761,000 acres, or slightly over three-quarters of a million acres. This is the first five-year period that has recorded such

a decline, according to census records. It is reasonable to suppose that price had some influence on this result. During this same period the total area in field crops increased by 177,000 acres, so that some other field crops must have been substituted for wheat. Acreage of barley in 1936 was some 500,000 more than in 1931 and the area in oats nearly 400,000 acres more than in the earlier year.

Since 1928 an estimate of the new breaking in the prairie provinces has been annually recorded. During the first five years of that period, that is from 1928 to 1932, the average area of new breaking added annually was 1,267,000 acres. During the last five years, from 1933 to 1937, this annual addition averaged 460,000 acres. This slowing up in the rate of expansion has been to a certain extent attributable to price and has no doubt also had some influence on the reduced yields per acre, as the proportion of new land has been smaller in recent years.

Census figures of 1936 show a marked increase in cattle in the Prairie Provinces as compared with 1931. The increase in total cattle amounted to over 900,000, or 31 per cent, while the increase in cows in milk or in calf was some 427,000 or 35 per cent. Some decline in number of hogs was recorded, but this may be partly due to the recurrence of hog cycles, which prevents census years only from being as fair a measure of hog production as other classes of live stock. Generally it is apparent that considerable switching away from growing grain for sale occurred during the period from 1931 to 1936. This is important, as many of those who discuss the wheat problem maintain that there are no alternative possibilities applicable to western Canada. This assertion has been so frequently made that the authors no doubt believe it themselves by this time. That, however, is not important; but what is more dangerous is that they may have by this time persuaded some of the farmers themselves to believe it.

Past records reveal that when wheat is over a dollar a bushel at the farm, no other line of farming receives much attention in Western Canada. Records also reveal that a period of low wheat prices expands other lines of farming. There are well known limits to the amount of switching possible. That some is possible has been demonstrated during the period 1931–1936. Why we know it is possible is because it has been done.

The development of other lines of farming is, in the long run, the salvation of the grain grower. There is no method of getting rid of a grain surplus equal to turning it into meat and dairy products. Those who have advocated this method of treating the wheat problem will no doubt, in the long run, prove the best friends of the grain growers generally, as it will promote a better balanced agriculture.

THE EFFICIENCY OF THE GRAIN GROWERS

Having in mind a better balanced agriculture and conceding that the national industry became unbalanced from 1916 to 1930, then, it may be of interest to examine the development of the technique of wheat growing in particular and grain growing in general during recent years. The method of growing grain has altered greatly in recent years. In 1910 the number of bushels of grain grown per person employed in agriculture averaged 780 bushels for the three prairie provinces. In 1920 the amount per person engaged in agriculture was 1,180 bushels, and in 1930 was 1,388

bushels, or nearly twice the amount per worker produced in 1910. This increase has been made possible by larger farms and more machinery. This season the author saw some wheat that was harvested with a "header" running 4 bushels per acre and good for a grade of No. 3. The only possibility of profitably harvesting such a light crop was with a header, as there would be no chance of binding such a light crop into sheaves. The future of wheat growing in dry areas is based on the modern machinery now available, the only method physically possible or economically profitable to garner such light crops. This is in line with the recommendations of a committee that has investigated the problems of the "dust bowl" of the United States for the past three years. This means that the only possible way of profitable wheat growing in dry areas is by large mechanized farms. In Australia, where the rotation in the dry areas, according to Sir Daniel Hall, is one year wheat, one year weeds, and one year fallow, it was found a long time ago that a family wheat farm in the dry area must consist of around twelve hundred acres.

NON-RESIDENT FARMS

If grain growing in dry areas is of necessity a mechanized job, then, there would appear to be no need for the operator to live on that particular farm throughout the whole year. Such a farm could be run most economically in connection with another farm where live stock could be kept and some returns secured during the winter months. There is no reason whatever why a small irrigated farm devoted to beef raising could not be operated in connection with a large grain-growing mechanized concern. Perhaps this is developing, as the 1931 census lists the non-resident farms of Canada as follows.

NON-RESIDENT FARMS

—	—	Percentage of total
Canada	57,191	7
P.E.I.	779	6
N.S.	1,415	4
N.B.	969	3
Quebec	9,338	7
Ont.	14,556	8
Man.	3,905	7
Sask.	16,427	12
Alta.	9,298	10
B.C.	504	2

These figures show that nearly half of the non-resident farms are located in the two provinces of Saskatchewan and Alberta. Again, the possibility of this procedure is maintained largely because it is already being done.

The practical doubling of the output of grain grown per worker in agriculture in the Prairie Provinces in twenty years is striking testimony of the increased efficiency of the grain grower. Yet if Canada is to maintain a major portion of the at present limited requirements of international trade in competition with countries such as Argentina, where we are told two-thirds of the crop is now grown within eighty miles of the seaboard, every possible means of increasing the efficiency of production will be necessary.

Recent census returns reveal some of the results of the half decade from 1931 to 1936 on the agriculture of the three Prairie Provinces. This record should be studied carefully by all interested in the status of the

agricultural industry of Canada. Some of the main points from these records are here summarized:

Trends 1931-36 Prairie Provinces[3]

Census returns of 1936 reveal that during the half decade from 1931 to 1936:

1. The value of land in the three Prairie Provinces fell by $328 million, or 22 per cent.
2. The number of farms operated by owners fell by 6,958, or by 3.7 per cent.
3. The number of renters rose by 14,448 or 34 per cent.
4. The number of farms partly owned and partly rented rose by 4,620 or 10 per cent.
5. Considering only the entirely owned and the entirely leased farms, 4 million acres passed from ownership to leasehold in the five years, or a gain in leasehold of 24 per cent.
6. The total number of farms increased by 14,444, or by 4 per cent.
7. The acres in field crops increased by 177 thousand acres, or 0.4 per cent.
8. The area devoted to wheat fell by 761,000 acres, or 3 per cent.
9. The area of new breaking was estimated at 1,300,000 acres in 1931 and at 473,000 acres in 1936, a decrease of 71 per cent.
10. The number of milk cows increased by 427,000, or 35 per cent.
11. The total number of cattle increased by 900,000, or 31 per cent.
12. The number of hogs decreased 600,000, or 25 per cent.

Land Value

During the five years 1931 to 1936, land values declined in the Prairie Provinces over $300 million, or over $1,000 per farm. This record warrants an examination of where land values were before this decline occurred. The following table shows the record over a long period of time.

LAND VALUES PRAIRIE PROVINCES

—	Area occupied millions of acres	Total value of land in farms millions of dollars
1911	58	$1,238.
1921	88	2,051.
1926	89	1,574.
1931	110	1,500.
1936	113	1,172.

This almost incredible record shows that while the area became almost twice as great since 1911, the total value actually decreased during that time; since 1921 an addition of 35 million acres was accompanied by a loss in land value of $879 million.

The expansion in area in the period here referred to occurred during the decade from 1911 to 1921 and the half decade from 1926 to 1931. Yet during the later period an addition of 31 million acres coincided with an actual decline in value of the total occupied area. During the two post-war depressions, that of the years 1921 to 1926, and from 1931 to 1936, expansion was limited and the decline in land values marked. The period from 1911 to 1936 gives the best example of people running fast to keep from slipping backward that has come to my notice.

[3] Canada Year Book 1937, pp. 272-273.

Wheat Area

Wheat growing has absorbed the major portion of the expansion in farming in Western Canada. The area of wheat shows a somewhat similar picture to that of the expansion of total area. During the period from 1931 to 1936 the area devoted to wheat declined about three-quarters of a million acres. This was the first five-year period that registered a decline, and the price prevailing is probably ample explanation. During that period, 1931 to 1935, returns per acre from wheat averaged about six dollars, which may be compared with the period 1925 to 1928 of $18.50, or over three times the return per acre of the later period.

The reduction in returns per acre to less than one-third in the later period as compared with the previous years was due partly to yield per acre and partly to lower prices. In the early period the yield averaged 18.4 bushels and in the later period 12.9 bushels. In the first period the price at the farm averaged $1.01 per bushel, and in the later period 48 cents per bushel. The reduction in return per acre was 37 per cent due to yield and 63 per cent due to lower price.

Whatever was the cause, it is useless to expect farmers to be able to retain sufficient of the returns from prosperous periods to maintain purchasing power in bad times when the variation is as great as this record shows. Insurance against crop failure has been applied successfuly, but insurance against price declines is a more difficult matter. Perhaps it is not impossible.

Cause of the Price Decline

The cause or causes of the much greater fall in prices of farm products and the prevalence for almost exactly seven years of the great discrepancy between prices of farm products and some other goods cannot be omitted from this survey.

The prices of farm products fell farthest and stayed down longest because there were few artificial props to sustain them. The bargaining power of the purchasers of farm products was greater than was that of the vendors during this time. Why? On account of the artificial supports which stabilized some other prices. Two of these artificial supports must be mentioned.

First, we have the tariff, which expects the farmer to take world prices, to produce a surplus to secure world prices, and to exchange his products at world prices in the domestic market for goods some of which are provided him at a higher price on account of being provided in a protected domestic market. The result is that the farmer buys some of his raw materials in a protected market and is expected to sell his finished product in a free and open market.

Second, the bargaining power of the farmer is weak on account of bargaining individually. As compared with this condition, we have other industries using a greater or lesser degree of collective bargaining. As a result, farm wages were reduced, both in the depression of 1921 and the later one we are now discussing, to a much greater degree than wages in other lines of activity.

Wages

In 1910 yearly farm wages, including the value of board, amounted to 83 per cent of the yearly earnings in manufacturing. By 1915 the proportion was 67, in 1919 it was 83, and in 1922, it was 63 per cent. From 1930 to 1934 the proportion declined from 60 to 40 per cent. During the four years from 1931 to 1934 inclusive, the proportion averaged slightly less than 42 per cent.

There is no argument here that the proportion was desirable or the reverse in 1910 or in any other year. What is maintained is that the *trend* has been definitely and distinctly against agriculture. If the proportion was desirable in 1910, then it was decidedly out of line during these two depressions and particularly during the recent one.

Such a result indicates that there is some underlying cause. The cause is the lack of any degree of strength in bargaining power on the part of the farmer. The weak bargainer is unable to pass on overhead, such as taxation. The farmer would add such items to price, if possible, but without collective bargaining there is small chance of it. Therefore the prices of farm products fell first and farthest and stayed down longest on account of:

1. The farmer having limited financial power and unlimited liability—dealing with corporations directly organized to secure ample financial power and limited liability.
2. The farmer dealing individually and indirectly with labour in industry which uses collective bargaining power.
3. The farmer dealing individually with stronger groups had small chance of maintaining prices in order to pass on taxes or other increased costs to the consumer of his products.

One of the results of the great discrepancy between prices of farm products and those of other things was that the net return to agriculture for the country as a whole was cut down to much less than half of what it had been prior to the price decline. For the six years from 1931 to 1936 estimated net returns averaged $570 million; whereas in the six preceding years the average was over $1,300 million. The three-quarter of a million farms in Canada in 1931, employing one and one-eighth million workers and cropping 60 million acres besides pasturing some nine million acres, had an average of $570 million per year from farming. This net figure is arrived at by making deductions[4] from the value of all products for feed fed to live stock, seed and fruit and vegetables used in the home. The net figure is expected to provide payment for hired labour (valued at $100 million in 1930), payment for the entrepreneur—in this case the farmer and his family, who do the major portion of their own work—purchase equipment, keep up repairs and provide the return (if any) on the investment. It is clear that the term *net return* should not be taken too seriously in the light of these figures.

Another result has been that returns on investment in agriculture do not exact so great a share as formerly, and for the reason that the proportion

[4] Monthly Bulletin Agr. Statistics, March Numbers.

of the national wealth invested in farming has recently grown smaller and still more beautifully less. Let the following records tell the tale.

PROPORTION OF NATIONAL WEALTH INVESTED IN AGRICULTURE

	1921†	(000)s 1929*	1933*
Total national wealth	$22,195,302	$31,275,814	$25,768,236
Total invested in Agriculture	7,982,871	7,939,477	5,563,790
Per cent of total	35.97	25.39	21.59
Value of urban real estate	5,751,505	8,251,011	6,913,530
Per cent of total	25.91	26.38	26.83

* Canada Year Book 1937, p. 862.
† Canada Year Book 1926, p. 803.

Since 1921 the proportion of the total national wealth credited to agriculture has declined from 36 to 22 per cent; hence 1921 investment in agriculture has declined two and a half billion in round numbers, while urban real estate has increased in value over one billion. Now urban real estate is more valuable than the total investment in agriculture, including the 160 odd million of acres now occupied as farm land. The marked reduction of the value of the agricultural plant has resulted in the practical disappearance of the credit of the industry. Hence another result of the past record is the disappearance of the customary sources of farm credit, formerly private capital. Provision of credit for carrying on farming has become more and more dependent on public funds provided by federal agencies.

SUMMARY AND SUGGESTIONS

Recent developments reveal that agriculture is not sufficiently prosperous to promote expansion. Under such conditions anticipation of expansion is hopeless. What is required is a new national policy—a national policy depending less on export of surplus farm products and more on forest and mineral products, where we have equally great advantage in natural resources and where foreign competition is less keen.

Of course there is an alternative method, namely, that of lessening the cost of production of farm products in order to enable a larger share of the world market in exports of farm products to be secured. Such a policy is unpopular with urban industry which is important in supplying equipment for farmers, transporting and processing farm products. Judging by the records examined, there is small chance of such a policy being followed. Hence the necessity of being contented with a smaller share of the world market for farm products and greater dependence on other exports.

Growing grain for export with the mechanized methods necessary to keep costs down does not offer much promise of employing many workers. On the other hand, turning surplus grain into meats and dairy products offers an opportunity not only of getting rid of surplus grain—when there is a surplus—but also employs more labour.

The greatest assistance to the wheat and grain grower would be the expansion of other industries that employ labour and increases the number of workers and the expansion of other lines of farming besides grain growing where dependence on world markets is not so great. Such a policy is advanced as a possible alternative to a bonus or minimum price set on a product that has been produced during the past few years below production costs and may again be in that category.

Further, there is both a guide and an opportunity of regulating or restricting the amount of wheat grown in Western Canada if and when the authorities wish to follow the guide and exercise the regulation. The guide to the advisability of sowing wheat is the amount of moisture stored in the subsoil the previous year. It is admitted that this guide is not infallible. Yet it is generally conceded that it is a fair criterion. The possibility of regulation or restriction comes from the present dependence on federal funds to provide seed. The stipulation that funds for seed would be supplied only to those whose land was well prepared might be used and will have to be resorted to when the public tires of furnishing funds for so risky a venture.

The expense of handling exportable surpluses of farm products, whether in the raw products of grain or in more concentrated forms such as meats, must be reduced. It is begging the question to argue that these expenses are now at a minimum. These expenses may be at a minimum if the present rates of wages are maintained in industry. On this basis a smaller share of the world market for farm products may be anticipated. If it be considered necessary or advisable to expand or even retain a share of the world market for farm products, some reorganization may be necessary in other industries than farming.

Finally, the taxation of the farmer must be lightened. No reference is here made to the income tax, which some farmers claim they would like to pay provided they had the income. And the reference is not restricted to the personal property tax, which degenerates into a real estate tax burdensome in many cases, but includes the indirect taxes, the incidence of which is so difficult to trace, but which are passed on in the price of the product by those who have the greater bargaining power.

EFFECTS OF SOME FIELD PLOT TREATMENTS ON DROUGHT SPOT AND CORKY CORE OF THE APPLE[1]

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In the spring of 1931, a number of field plots were established in the Kelowna Project apple orchard, at Kelowna, British Columbia, for the purpose of studying the effects of various treatments on drought spot and corky core of the apple. As a result of this work, it has been found (3, 4) that both of these disorders are due primarily to a deficiency of boron. McLarty (3) has reported that when chemicals containing boron (such as boric acid and manganous borate) were injected into the trunks of the trees, both drought spot and corky core were completely eliminated in the following year's crop. McLarty, Wilcox and Woodbridge (4) have reported that applications of boric acid or of borax to the soil have also brought about complete control. Where the trees have not been treated with boron, however, the severity of the disorders has been influenced in one direction or the other by certain of the other field plot treatments. The results of these treatments are reported in this paper. In addition, there are presented certain correlations between the severity of drought spot and other tree characteristics.

DESCRIPTION OF ORCHARD

The orchard consists of 23 acres of apple trees, of the following varieties: McIntosh, Jonathan, Delicious, Newtown, Duchess and Wealthy. The permanent trees are 30 feet apart; and where fillers are present (in one plot), the trees are 21 feet apart. Most of the trees in the plots were 19 years old when the tests were started, though there were a number of younger trees where replantings had been made. Drought spot, corky core and their related disorders were quite prevalent in all of the experimental plots.

The soil throughout the plots is a sandy loam, ranging for the most part from 1 to 3 feet in depth, and is underlain by a mixture of coarse sand and gravel. In certain small areas, the gravel comes almost to the surface. The moisture holding capacity of the soil above the gravel averages about 16%. Except in those plots receiving fertilizers, the pH of the soil ranges from 6.8 to 7.1. Analyses made on samples collected from untreated plots showed the following concentrations of available nutrients, expressed as parts per million of dry soil:[3]

NO_3	1.31 to 15.60 p.p.m.
PO_4	1.74 to 11.50 p.p.m.
K	30.80 to 69.40 p.p.m.
Ca	12.80 to 33.10 p.p.m.
B	0.08 to 0.20 p.p.m.

[1] Contribution No. 485 from the Division of Horticulture, Experimental Farms System, Canada.

[2] Graduate Assistant in charge of the horticultural work of the Kelowna project.

[3] The soil samples were taken with an auger, down to the gravel. The solution for analysis was made by mixing one part by weight of soil with an amount of water equal to 25 times the moisture holding capacity. The mixture was saturated with CO_2 for 24 hours, then filtered through a Livingston atmometer. The analyses have been made by Mr. C. G. Woodbridge, chemist of the Physiological Disorders Investigation at Summerland.

Tests with HCl gave no evidence of free carbonates, either in the top soil or in the gravel below. The cover crop consisted at the start of the tests largely of alfalfa; but over the 6-year period the alfalfa has mostly died out and been replaced by grasses, weeds, and occasional patches of sweet clover.

Except for the differential plot treatments, uniform cultural practices have been maintained throughout the orchard. The cover crop has been disced once a year, in the spring. The irrigation furrows have been spaced 3 to 4 feet apart. Irrigation water has been applied every 10 to 12 days during some 4 months in the summer, with a 12-hour run at each application. The total amount of water thus applied has varied each year over the orchard as a whole from 30 to 52 acre inches per acre, depending on the season's requirements. In addition, the annual precipitation (mostly in the dormant season) has ranged from 10.2 to 15.4 inches during the 6-year period. Except in the fertilizer plots, no fertilizers have been applied. The pruning practised has been moderately light.

Over one-half of the orchard was divided into plots in the spring of 1931, and differential treatment was started on about two-thirds of them, the balance being retained as checks. The plots ranged in size from 0.2 to 0.5 acre, and the number of treated trees in each plot from 6 to 21. Between each pair of plots, a "buffer" row has been maintained, receiving on either side the respective plot treatments. For the most part, the plots have contained a sufficient number of trees of the same variety and of similar size and condition to warrant the drawing of conclusions from the results obtained, but in certain cases they have not. Special note will be made of such plots when their results are reported below.

RECORDS TAKEN

During the past 6 years, individual tree records have been taken on all of the plot trees. These records include the trunk circumference, terminal length, terminal diameter (up to 1934), percentage bloom, percentage set of fruit, crop of saleable fruit, percentage drought spot, and percentage corky core. In addition, notes have been taken on foliage condition, twig die-back, and various other characteristics of the trees. The methods of recording the growth, bloom, and fruiting have been described by the author in previous publications (5, 6), and will not be repeated here. The percentages of drought spot and corky core have been recorded at picking time, the procedure used being as follows: Each tree was divided into quarters, in accordance with the points of the compass. From the ground, 10 apples were selected at random from each quarter of the tree, and 10 more were selected from the top centre, making a total of 50. The number in this 50 that showed drought spot were counted. They were then cut and the number showing corky core were counted. The figures thus obtained have been multiplied by 2 to give the respective percentages.

PLOT TREATMENTS AND RESULTS

Check Plots

The untreated plots are used throughout this report as a basis on which to judge the effects of the differential plot treatments. The variability between and within these plots is accordingly of great importance.

By way of illustrating the variation between plots, the average percentage drought spot in each of four check plots containing McIntosh trees is charted in Figure 1A. The average is, in each case, that of the McIntosh trees only. In Figure 1B is charted the percentage drought spot on each of five McIntosh trees in one untreated plot. It will be seen that there has been a good deal of variability both between and within plots. These charts also illustrate the general tendency of the percentage drought spot

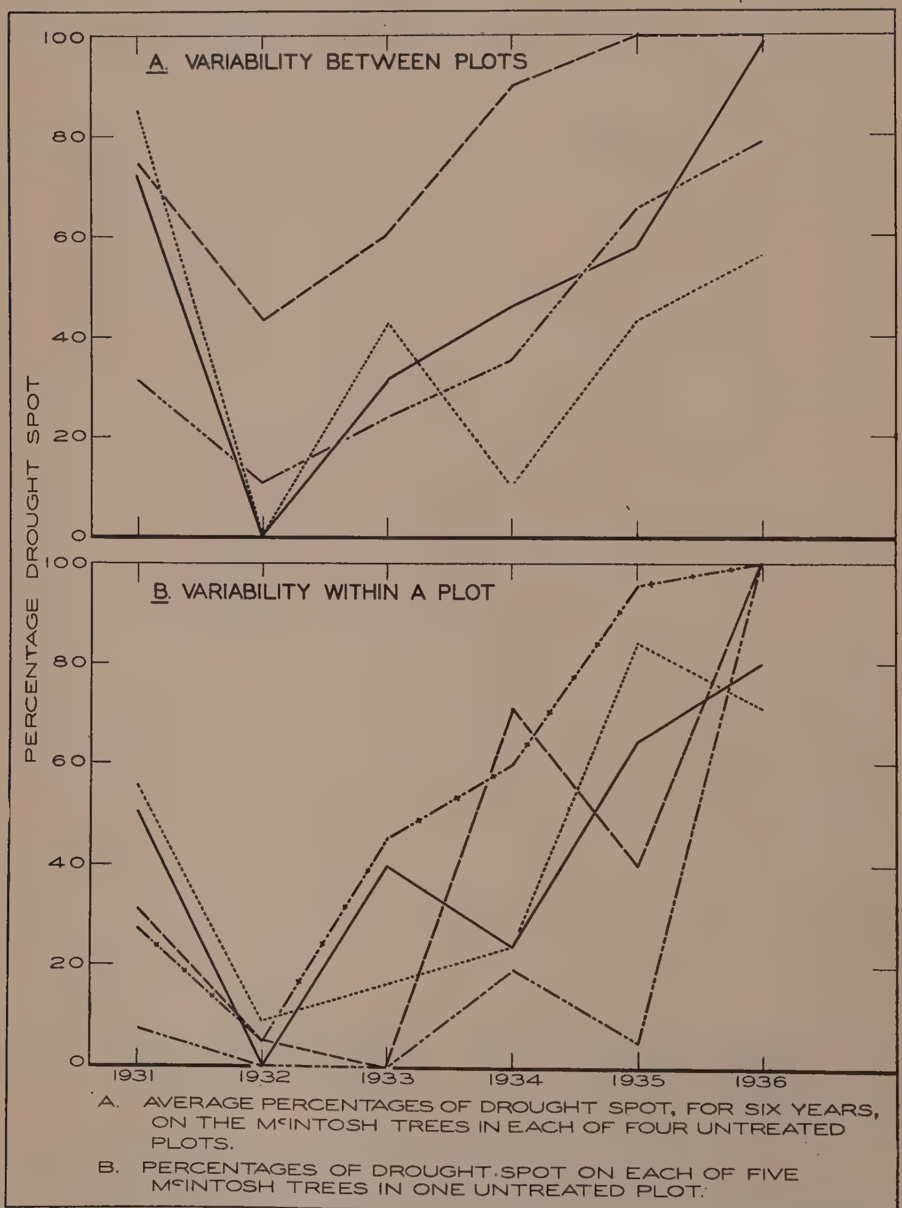

FIGURE 1. An illustration of the variability in percentage drought spot, both between plots and within a plot.

in the orchard as a whole to drop very low in 1932, and to rise fairly steadily again each year since that time. The corky core tendencies have been very similar to those of drought spot. It is evident from these results that good commercial care, as applied to the check plots, has not served to cure drought spot or corky core.

Variation in Water Supply

In his preliminary work on drought spot and corky core, McLarty (1, 2) found that these disorders could be influenced a great deal by the moisture conditions in the soil. His findings have accordingly been followed up by a number of treatments designed to test various methods of irrigation, including not only a variation in the total amounts of water applied during the season, but also a variation in the amount per irrigation with the total during the season kept constant. These treatments have been applied to three series of plots. In the first series (4 plots) a total of 32.5 inches in depth of water (32.5 acre inches per acre) has been applied during the season to each plot, while the time between irrigations has been arbitrarily set at 5, 10, 15, and 20 days in the respective plots. The amount of water applied at each irrigation has been 1.33, 2.67, 4.00 and 5.33 inches respectively. In the second series (3 plots), the soil has been wetted to the gravel every 5, 10, and 15 days respectively. In the third series (4 plots), one plot has been irrigated to the gravel every 10 days, and after each application the depth of water applied has been calculated and the other three plots given $\frac{1}{4}$, $\frac{1}{2}$ and twice that depth respectively. In each of these 11 plots, the water has been measured with a miner's inch box devised by Mr. R. C. Palmer of the Dominion Experimental Station at Summerland, and has been carried along the top of the plot in a small secondary flume, as illustrated in Figure 2.

In the first two of these plot series, the results on the individual plots have not shown sufficient differences in the trends of drought spot or corky

FIGURE 2. Method of measuring the water and distributing it on each of the special "water plots".

core to justify any conclusions. Any differential effects that there may have been as a result of the variations given in the water supply have been hidden by the strong tendency (since 1932) of all the plots to increase in drought spot and corky core. In the third series, however, the differences have been quite marked. In the two plots receiving the lesser quantities of water, severe wilting has occurred, the growth has been poor, the fruit has been small, drought spot has been severe, and corky core has been especially severe. Wilting of the trees early in the season has in all cases been followed by severe corky core the same year, both in these two plots and in other sections of the orchard. On the other hand, doubling the supply of water over that necessary to wet the soil has made little difference in either drought spot or corky core. Owing to the gravelly nature of the subsoil, the excess water in this plot has readily drained away. In none of the water plots has the pH of the soil shown any material change, being in 1936 still within the range 6.8 to 7.1.

The drought spot trends are illustrated in Figure 4A, and the corky core trends in Figure 4B. At the bottom of the chart is shown the number of trees used in constructing each line of trend. Restriction of the data used to those of the one variety lessens considerably the number of trees entering into each average, but gives a truer picture of the trends than where all the trees in the plot are averaged. In each case, the other varieties have shown the same trends, though the percentages of drought spot or corky core have been either higher or lower than those of the variety used. The same holds true of the other charts to follow. The general effects of a water deficiency on tree growth and die back are illustrated in Figure 3.

Application of Commercial Fertilizers

Before the start of this experimental work in 1931, a good deal of evidence had been obtained in the Okanagan Valley to the effect that drought spot and corky core could be influenced by stable manure and by com-

FIGURE 3. Type of growth induced by a deficiency of water, on trees subject to a drought spot condition.

mercial fertilizers. McLarty (1) reported in 1927 that manure had increased the severity of corky core. Observations in grower-owned orchards had likewise indicated that in some cases nitrogen had had a deleterious effect, and potash a beneficial effect. Separate tests of the three primary fertilizing materials had however not been conducted in any systematic manner. It was accordingly decided to lay out 4 series of plots, to be treated with nitrogen, phosphate, potash and mixed fertilizers respectively. These materials have all been applied annually, in the spring before the

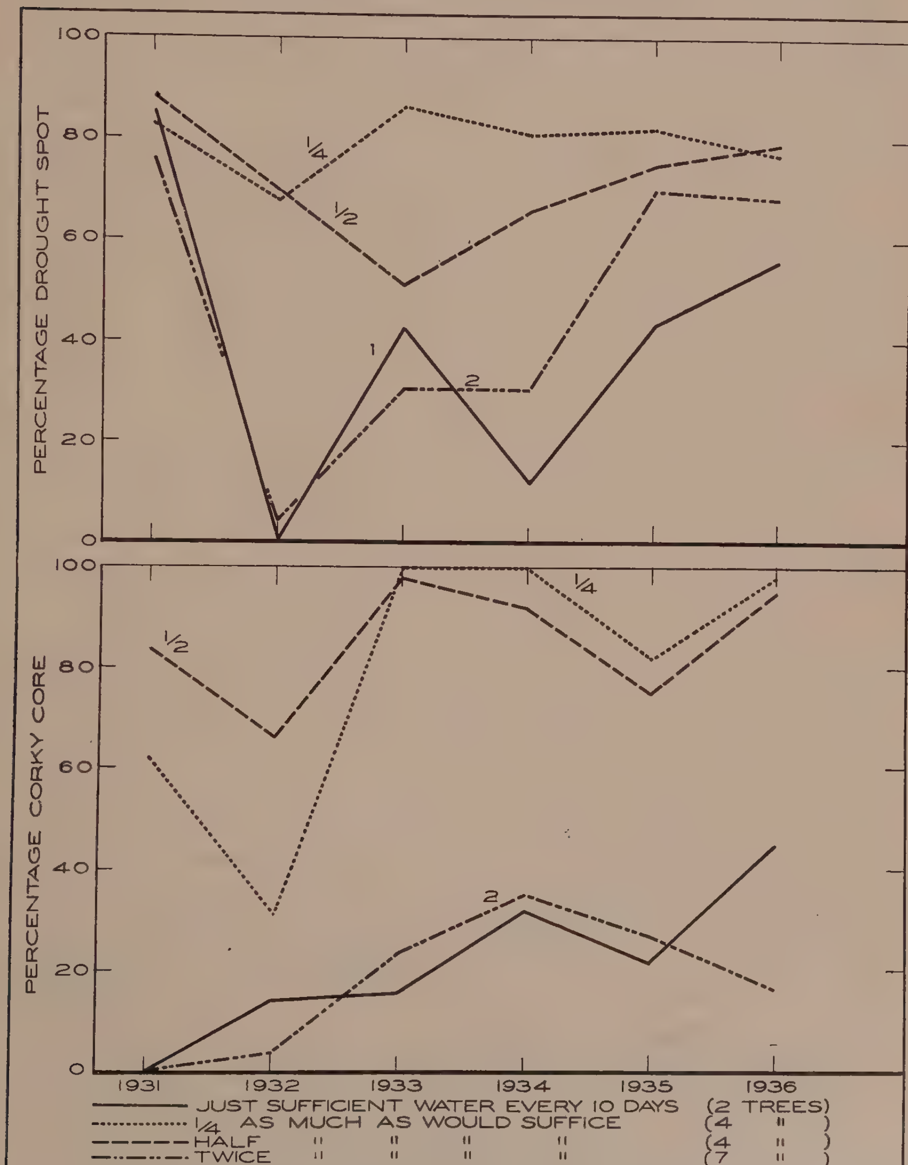

FIGURE 4. Effects on drought spot and corky core of a deficiency of water. McIntosh trees only.

start of the first irrigation. They have been spread evenly over the surface of the ground from near the trunk out to or just beyond the outermost spread of the limbs.

Nitrogen has been applied in the form of sulphate of ammonia, at annual rates of 6 pounds per tree in one plot and 15 pounds in a second plot. Both rates of application have increased the vigour of the trees markedly, and have also increased the severity of the drought spot. The trees are all of the Delicious variety, which seldom exhibits any corky core and which is not usually as severely affected by drought spot as is the McIntosh or Jonathan. The drought spot trends are shown in Figure 5. The moderate applications of nitrogen have acidified the soil to an average of pH 6.3, and the heavy applications to an average of pH 5.2.

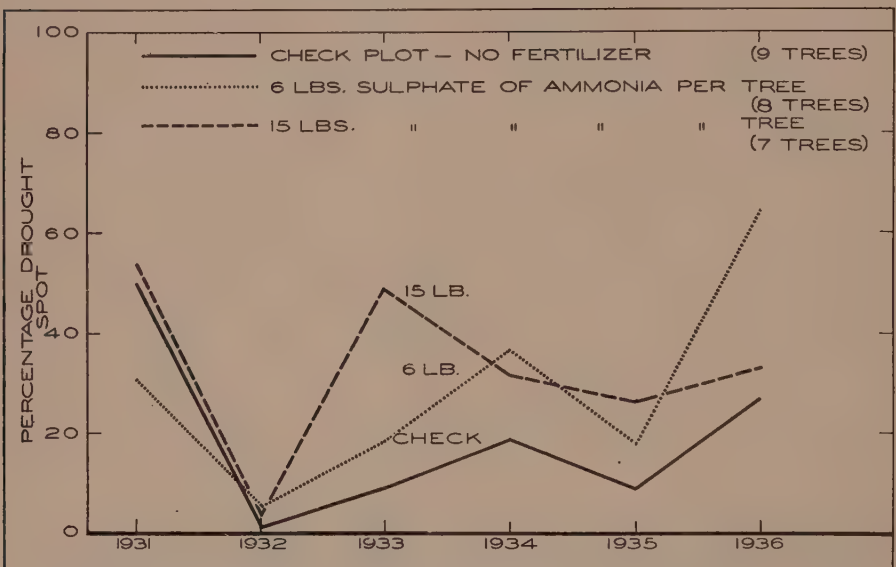

FIGURE 5. Effects of annual applications of sulphate of ammonia on percentage drought spot. Delicious.

Phosphate has been applied in the form of ordinary superphosphate, at annual rates of 4 pounds and 20 pounds per tree in two respective plots. The trees have been mostly Jonathan, with some McIntosh. In both of the treated plots, drought spot and corky core have been especially severe. However, the soil is somewhat shallower than in the check plots, so that it is questionable just how much of the results can be attributed to treatment. It will be seen in Figure 6 that the 4-pound plot was worse at the start than were the other 2 plots. The soil has been rendered slightly more acid by the superphosphate (pH 6.6 to 6.8).

Potash has been applied in the form of muriate of potash, in one series at annual rates of 2 pounds and 20 pounds per tree in 2 respective plots, and in a second series at rates of 10 pounds and 20 pounds per tree. In the first series of plots, the trees are all Delicious. In this series, the heavy applications have been accompanied by quite definite decreases in percentage drought spot. Since however the soil in the 20-pound plot is a

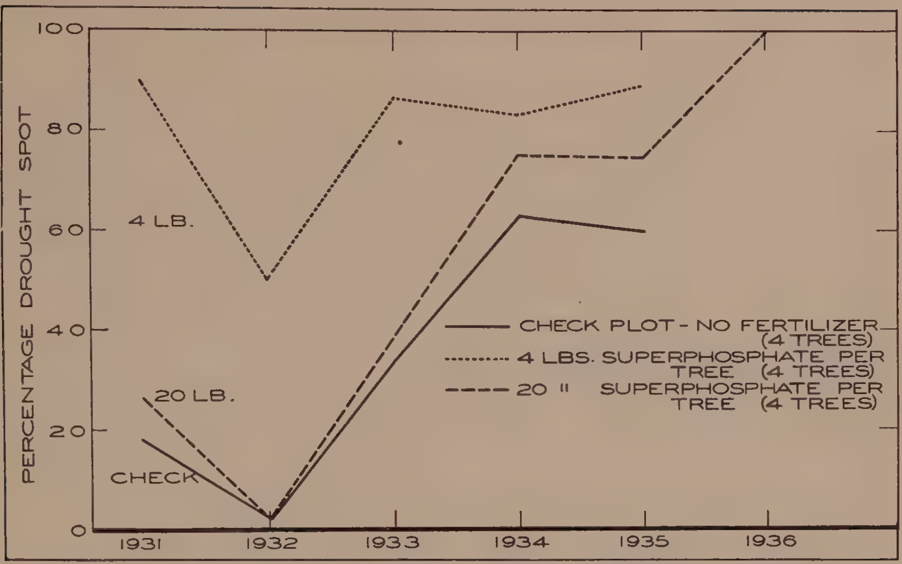

FIGURE 6. Effects of annual applications of superphosphate on percentage drought spot. Jonathan trees only. Treatment on two of the plots was discontinued in 1936.

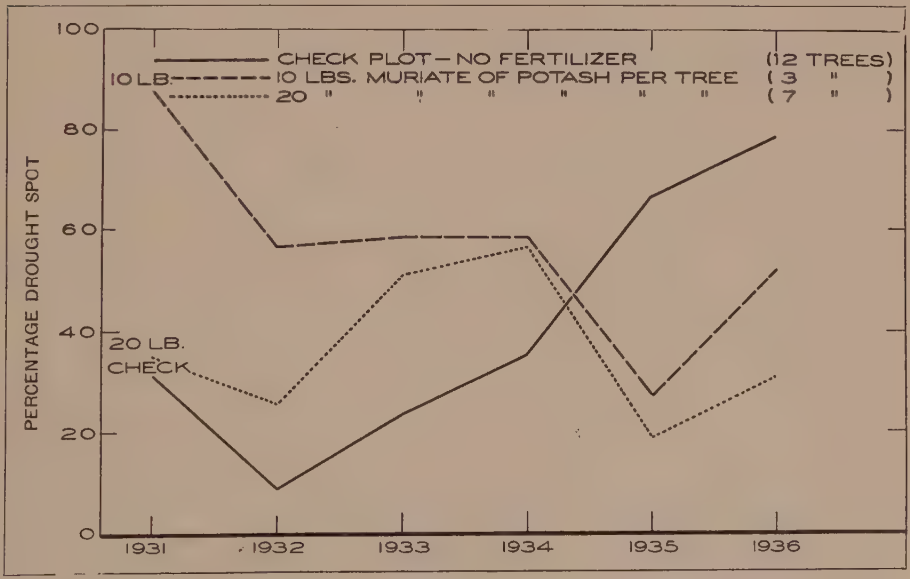

FIGURE 7. Effects of annual applications of muriate of potash on percentage drought spot. Treatment started in 1934. McIntosh trees only.

little deeper than in the other 2 plots, the results may not all be attributable to treatment. The second series, in which the trees are McIntosh and Jonathan, was not started until 1934. In the 2 treated plots, there was a drop in percentage corky core in 1934, and a drop in percentage drought spot in 1935. The drought spot trends in this series are shown in Figure 7. There has been no apparent effect of the treatment on the pH of the soil.

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It might be noted that the muriate of potash used in this work has been found to contain 0.03% B_2O_3 as an impurity.[5]

Two different mixtures of fertilizers have been applied in two separate plots. In the first plot the annual rates of application have been 6, 4, and 2 pounds respectively of the three fertilizers, giving 12 pounds per tree of a 10-5-8 ratio. In the second plot, the rates have been 15, 20, and 20 pounds respectively, giving 55 pounds per tree of a 5-6-18 ratio. The trees in this series are Jonathan and McIntosh. The 10-5-8 fertilizer has increased vigour markedly, but appears to have had little effect on drought spot or corky core. The 5-6-18 fertilizer has likewise increased tree vigour. It produced at first a definite improvement in drought spot and corky core; but by 1935 there was once again as much of each showing as in the check plot. The trees in all three plots were treated with boron in 1936, and the drought spot was thus eliminated. The pH of the soil has been lowered to around 6.0 in the 10-5-8 plot, and to around 5.0 in the 5-6-18 plot.

Pruning, Root Pruning, Tree Crowding

When the field plot tests were being laid out, it was thought that the ratio of top to root might influence drought spot and its related disorders, through the effect of this ratio on the balance between the requirements and the supplies of water and nutrients. Accordingly, treatments were initiated such as to change this ratio from the normal. These treatments included pruning of the top, pruning of the roots, and crowding of the trees, with the respective objects of reducing the top, reducing the roots, and preventing the free growth of both top and roots.

Three plots have been pruned with different degrees of severity: no pruning, moderate pruning, and severe pruning. No pruning has been accompanied by a lessened growth of shoot and trunk. Severe pruning, *i.e.*, the removal of about 25% of the wood and buds each year, has induced more twig growth for 2 years only: since 1932, neither the growth of the shoots nor that of the trunk has been any greater than with moderate pruning. Neither extreme of pruning has had any apparent effect on drought spot or corky core. All three of the pruning plots were severely affected with drought spot and corky core at the start of the experiments in 1931.

Six trees were root-pruned in the spring of 1931, by digging trenches around them down to the gravel: 2 at 4 feet from the trunk, 2 at 7 feet from the trunk and 2 at 10 feet from the trunk. Growth and production have been lessened in all cases, especially with the more severe treatments. There appears however to have been little if any effect on drought spot or corky core. A similar result has been noted where trees have been affected by crown rot or bad sunscald, *i.e.*, a lessening of vigour with little change in drought spot or corky core.

In a series of two adjacent plots, the filler trees were removed from one in the spring of 1931, but left in the other. The crowding of the trees in the latter plot has been accompanied both by a lowering of vigour and by a decrease in severity of drought spot and corky core, in comparison with the other plot.

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[5] Analysis by Mr. C. G. Woodbridge.

DROUGHT SPOT CORRELATIONS

By the use of dot diagrams and coefficients of correlation, studies have been made each year of the relationship between drought spot and each of the measurements representing tree growth and fruiting. The methods of making the correlations have been outlined by the writer in a previous paper (6). The trees used for these studies have been those in the untreated plots that have been affected with drought spot.

The coefficients of correlation between drought spot and either growth or fruiting have for the most part shown good uniformity in sign and significance from year to year. An exception was in 1932, when for some reason the percentage drought spot dropped so low that the correlations were not statistically significant. For the sake of brevity, the correlations reported at this time are being confined mainly to 2 years, 1934 and 1935, and to one variety, the McIntosh. They have been calculated from the field records on 50 trees of bearing age. In the results presented below, a coefficient of correlation is considered to be statistically "significant" when the odds are between 19 : 1 and 99 : 1, and "highly significant" when they are over 99 : 1.

Drought Spot in Successive Years

The coefficient of correlation between the percentage drought spot in 1935 and that in 1934 was +0.353, which is statistically "significant".

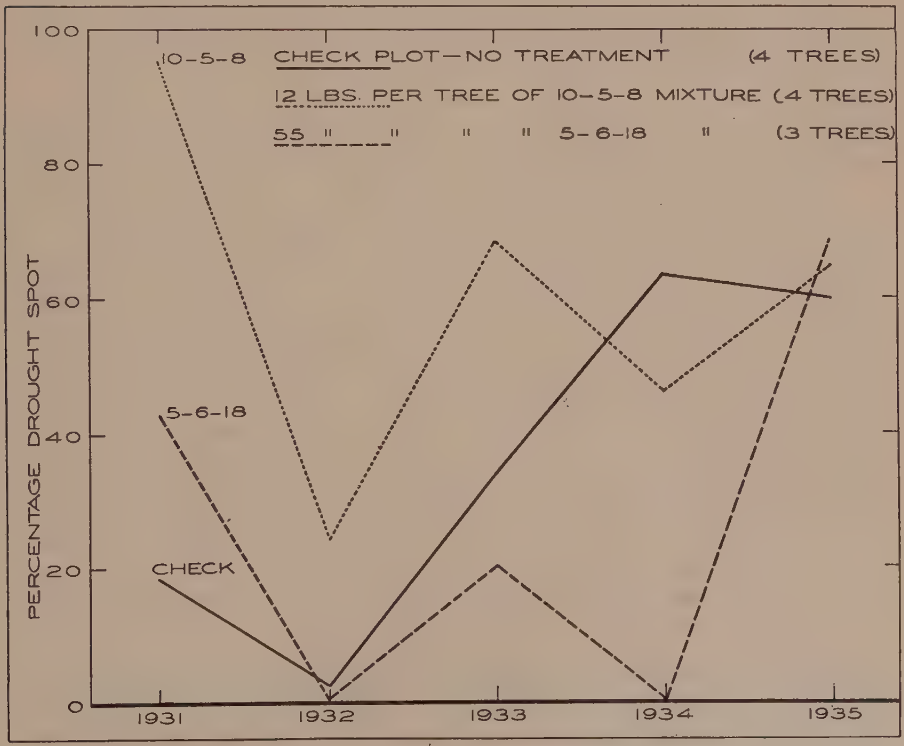

FIGURE 8. Effects of mixed fertilizers on percentage drought spot. Jonathan trees only. Treatment was discontinued in 1936.

This is an indication that in spite of all other factors that may have affected the drought spot, the disease has tended to be more severe in successive years on one tree than it has on another tree. The coefficient of correlation between the percentage drought spot in 1935 and that in 1933 was +0.501, which is "highly significant". This means that on the same tree, the disease has tended to be of the same degree of severity in alternate years more than it has even in successive years.

Drought Spot and Bloom

In order to study the relationship between the percentage drought spot and the percentage bloom in any one year, it has been found necessary to eliminate the general differences between trees in their susceptibility to drought spot and in their tendency to blossom heavily. This has been done in several ways, the most useful of which has been the "ratio" method described in a previous paper (6). When the percentage drought spot in 1935 was divided by that in 1934, and the same done with the percentage bloom, the coefficient of correlation between the 2 ratios thus obtained was −0.644. Substituting percentage set for percentage bloom gave a correlation of −0.586. Both of these coefficients are "highly significant". The indication is that there has been a very strong tendency for the fruit to be more severely affected with drought spot in the off year than in the on year, an indication borne out by general observation throughout a large number of orchards. This helps to explain the greater correlation noted above between drought spot in alternate years than in successive years. It also helps to explain the variation in percentage drought spot from year to year, as depicted in the plot tendency charts above.

Drought Spot and Tree Vigour

As just noted, biennial bearing has been found to have an effect on the percentage drought spot; and as previously reported by the author (6), it has likewise been found to have an effect on tree vigour. Thus in any study of the relationship between general tree vigour and susceptibility to drought spot, it is necessary to eliminate the effects of biennial bearing. This may be done by averaging the data for 2 or for 4 years. The following correlations have been obtained by averaging the McIntosh results for 1934 and 1935:

Coefficient of correlation between percentage drought spot and increase in trunk circumference	+0.340
Coefficient of correlation between percentage drought spot and terminal length	+0.432
Coefficient of correlation between percentage drought spot and growth index (increase in trunk circumference multiplied by terminal length[6])	+0.575

The first of these is "significant", and the second and third "highly significant". This means that the more vigorous trees have tended to be more severely affected with drought spot than have the less vigorous trees. It might be noted that although the trees used in these correlations have not been fertilized for at least ten years, they have been subject to wide variations in the proportion of legumes growing in the cover crop, which has been one of the primary factors influencing their degree of vigour.

[6] The use of the "growth index" has previously been reported upon by the author (7).

EFFECTS OF PLOT TREATMENTS ON THE RELATIONSHIP BETWEEN DROUGHT SPOT AND TREE VIGOUR

It was noted above that some plot treatments have been followed by an increase in drought spot, some by a decrease, some by neither. The same has held true with tree vigour. The effects on drought spot and vigour have, however, not been of the same type or of the same degree under the different treatments. In view of the high correlation between

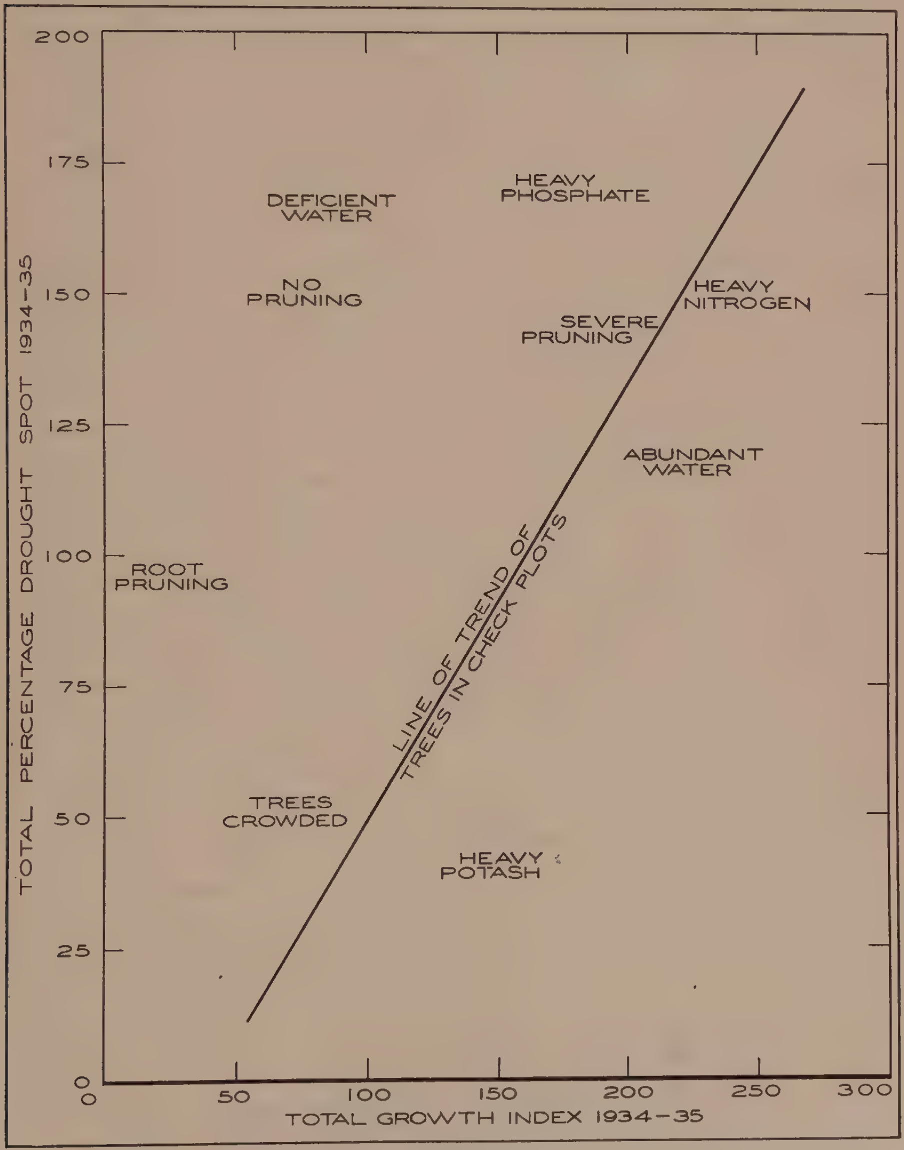

FIGURE 9. Effects of various treatments on the balance between percentage drought spot and tree vigour. The points designated represent the general positions of the McIntosh trees in the respective plots. The "heavy nitrogen" point has been estimated from its position on the Delicious charts. The "heavy potash" point is for 1935 only, multiplied by 2.

percentage drought spot and degree of vigour in the untreated plots, these differential effects of plot treatment attain considerable significance.

The method that has been used to study the effects of plot treatment on the relationship between drought spot and vigour has been, first, to chart the line of trend of the distribution obtained by plotting the one against the other in check plots, and then to note the general position of the plotted point for each tree in the treated plots. It can thus be determined whether any specific treatment has upset the normal relationship between drought spot and vigour as found in the check plots. By way of illustration, the line of trend for the McIntosh trees in the check plots during the two years 1934 and 1935 is shown in Figure 9. The total growth index for the two years is here used to represent general tree vigour. There is also shown the general position in the chart of the McIntosh trees in each of several of the treated plots. The number of trees used in determining these positions is the same as noted for the line graphs in Figures 4 to 7. The point marked "trees crowded" is for the plot where the filler trees were left in. Only two McIntosh trees were available to determine this position; however, the Jonathan trees in the plot assume the same general position in the Jonathan chart. The "heavy nitrogen" point has been estimated from its position in the Delicious charts. Since treatment in the "heavy potash" plot used was not started until 1934, the point shown was obtained by multiplying the 1935 results by 2.

An examination of the chart shows 3 general groups of treatments: (1) Those that have not changed the "normal" relationship between drought spot and vigour to any great extent. Heavy nitrogen, severe pruning, and crowding of the trees come in this category. The first has been accompanied by an increase in both drought spot and vigour. The second has had little effect on either, after 4 years of treatment. The third has been accompanied by decreases in both drought spot and vigour. It might be noted again that the trees in both the no-pruning and heavy-pruning plots showed severe drought spot at the start (*i.e.* in 1931). (2) Those that lie below the line of trend. An abundance of water appears to have increased the vigour somewhat, but has had little effect on drought spot. Heavy potash has decreased the drought spot without having had any apparent effect on vigour. (3) Those that lie above the line of trend. A deficiency of water has increased the drought spot and decreased the vigour. No pruning has decreased the vigour but has had little effect on drought spot. Heavy phosphate has had little effect on vigour, but has been accompanied by a high percentage of drought spot. As already noted, the soil is very shallow in this plot, and the results may not all be due to treatment. Root pruning has decreased the vigour markedly, but has had little effect on drought spot.

DISCUSSION

It has been shown by McLarty (3), and by McLarty, Wilcox, and Woodbridge (4), that drought spot and corky core as they occur in the interior of British Columbia can be readily controlled by treating with compounds of boron. There appears to be no doubt, accordingly, that a deficiency of boron is at the root of the trouble. This however does not preclude the possibility of other factors than the supply of boron having some influence on the severity of the disease. The results reported in this

paper do indeed point to such a possibility, for a number of the plot treatments have been accompanied by definite responses one way or the other in the severity of both drought spot and corky core.

It is not proposed at this time to attempt any explanation of the function of boron in the plant, or of its possible relationship to the above results. Some comment may however be made on the positive correlation between drought spot and vigour, and the apparent place of nitrogen in this relationship. An increase in the nitrogen supply, whether in the form of sulphate of ammonia or leguminous cover crops, has been accompanied by both increased vigour and a higher percentage of drought spot, in full accord with the balance found in the more vigorous trees in the check plots. Crowding of the trees, likewise, has lessened both vigour and drought spot, presumably through its effect on soil conditions. On the other hand, any decrease in vigour by other means than through the soil (*e.g.* no top pruning, severe root pruning, sunscald) has not been accompanied by a corresponding decrease in drought spot. It would thus appear that under the conditions encountered in these tests, the severity of the drought spot has been associated not merely with tree vigour as such, but rather more specifically with the supply of nitrogen.

Some comment should also be made on the partially beneficial effects of potash. As already noted, the muriate of potash used in this work has been found to contain very small amounts of boron as an impurity. It is just possible that this may explain the results obtained. McLarty (3) was unable to cure drought spot or corky core by the injection of potassium salts into the trunks of the trees.

A note of caution should be sounded with regard to the general application of the findings reported in this paper: the experimental results and the correlations are from trees which have all been affected in some degree by drought spot and its related disorders, and they cannot be applied to trees that have never been thus affected. Many orchards in the interior of British Columbia, for instance, have been dosed heavily with nitrogen without their showing any evidence of drought spot or corky core; while on the other hand, many orchards in a low state of vigour have been severely affected with both types of the disorder. However, in orchards where a tendency towards these disorders has been noted, an application of nitrogen or a deficiency of water has almost invariably been found to increase their severity.

SUMMARY

A large number of field plot treatments were initiated in the spring of 1931, in an attempt to find a cure for drought spot and corky core of the apple. These treatments have been continued for six years. Comparisons in the trends of drought spot have been made by the use of line graphs. Correlation studies have been made in the check (untreated) plots between drought spot on the one hand and amount of bloom and tree vigour on the other hand. The results reported are as follows:

1. A deficiency of irrigation water has decreased tree vigour, increased drought spot, and increased corky core markedly.

2. Fertilizer applications in heavy amounts (15 to 20 pounds per tree annually) have had both detrimental and beneficial effects. Sulphate of ammonia has induced both a more vigorous growth and more severe

drought spot. Superphosphate has had little effect on tree vigour, but appears to have increased drought spot somewhat. Muriate of potash has had no apparent effect on tree vigour, but has lessened the severity of the drought spot.

3. Severe pruning has increased tree vigour only temporarily. No pruning has decreased tree vigour markedly. Root pruning has decreased tree vigour even more so. None of these three treatments has had any measurable effect on drought spot. Tree crowding has lessened both vigour and drought spot.

4. Statistically significant negative correlations have been found between drought spot and percentage bloom, and positive correlations between drought spot and tree vigour. It is suggested that this last is due more specifically to the influence of nitrogen.

ACKNOWLEDGMENTS

The author wishes to express his indebtedness to Dr. H. R. McLarty, of the Dominion Laboratory of Plant Pathology at Summerland, who as officer in charge of the Physiological Disorders Investigation drew up the plans for these experiments, and who has assisted materially in the preparation of this report; and to Mr. R. C. Palmer, Superintendent of the Dominion Experimental Station at Summerland, for his guidance in the taking of the records and for his many helpful suggestions throughout the course of the work. Mr. M. S. Middleton, Mr. B. Hoy, and Mr. R. P. Murray, members with Dr. McLarty and Mr. Palmer of the Okanagan Physiological Disorders Committee, have also offered many valuable suggestions. In addition, the author wishes to acknowledge the assistance of Mr. C. G. Woodbridge, Chemist of the Physiological Disorders Investigation, in making the chemical analyses reported in this paper.

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PHYSIOLOGY OF APPLES IN ARTIFICIAL ATMOSPHERES[1]

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INTRODUCTION

The influence of artificial atmospheres upon stored fruits has been the subject of much investigation during the past decade, not only in relation to the practical problems but also to those of a more fundamental character concerned with the living activities of the plant. The notable work of Kidd and West (20) has seen its fruition in the present commercial development of gas storage for apples, and their studies together with those of Blackman and others (3, 14, 32, 37) have greatly contributed to the knowledge of the process of plant respiration.

This report includes the following considerations:

1. Respiration.
2. Biochemical changes.
3. Osmotic and permeability relationships.
4. Fungal activity.
5. Physiological disorders.

The results of the above investigations will be dealt with under separate headings.

MATERIALS AND METHODS

Storage Methods

Three varieties of apples were used throughout the main experiments; namely, McIntosh, Cox Grange and Golden Russet. The fruit was first placed in storage at 0° C. immediately after picking, and then removed to cellar storage conditions at a mean temperature of 4.5° C. at the end of October 1935. At this time samples of fifty apples for each treatment were placed in five-gallon cans equipped with two copper tubes, one of which extended to the bottom of the container; these were used for sampling purposes. The lids of the cans were heavily vaselined and thus rendered gas tight. Carbon dioxide and nitrogen were added directly from cylinders under pressure, the latter being used to reduce the normal concentration of oxygen. An Orsat gas analysis apparatus accurate within 0.2% was used for the analysis of the atmospheres. Analyses of the atmospheres were made daily and the containers ventilated in order to maintain the desired concentration of carbon dioxide. At the end of December 1935, the material was moved from the Kentville Experimental Station, N.S., to a storage cellar at Macdonald College, Quebec, where the temperature averaged 3° C. (±1°).

[1] In partial fulfilment of the requirements for the degree of M.Sc.
[2] Graduate Assistant.

The treatments and controls in air which were used are shown in the adjoining table.

Variety	Per cent CO_2	Per cent O_2	Per cent N_2	Average gas concentration during entire storage period	
McIntosh	2.5	18.5	79	2.6 CO_2	
McIntosh	5.0	16.0	79	4.5 CO_2	
McIntosh	10.0	11.0	79	9.1 CO_2	*Duplicate*
Cox Orange	—	2.5	97.5	2.1 O_2	2.5 O_2
Cox Orange	2.5	18.5	79	2.4 CO_2	3.1 CO_2
Cox Orange	5.0	16.0	79	4.8 CO_2	5.2 CO_2
Cox Orange	10.0	11.0	79	9.5 CO_2	9.6 CO_2
Golden Russet	5.0	16.0	79	4.0 CO_2	
Golden Russet	10.0	11.0	79	9.2 CO_2	

Two examinations were made, 25 apples being used in each case. In the first examination 10 fruits were frozen at −15° F. and the tissue ground up and stored in bottles for one week in the frozen condition until used for subsequent experiments. Another 10 fruits were set aside for acid, hydrogen ion concentration, and refractometric determinations.

In addition, several subsidiary experiments were undertaken in which the concentrations of carbon dioxide and nitrogen were adjusted to high levels for limited periods.

Respiration

The evolution of carbon dioxide from the fruit was measured by means of the weighed tube method, the equipment and methods being similar to that described by the author in a previous paper (10) with some modifications. The carbon dioxide absorbent, "Ascarite", a Central Scientific Company product, was substituted for the soda flake. This absorbent is the American equivalent of the B.D.H. product, "Carbosorb", both of which are used extensively in organic analysis. Figure 1 indicates the

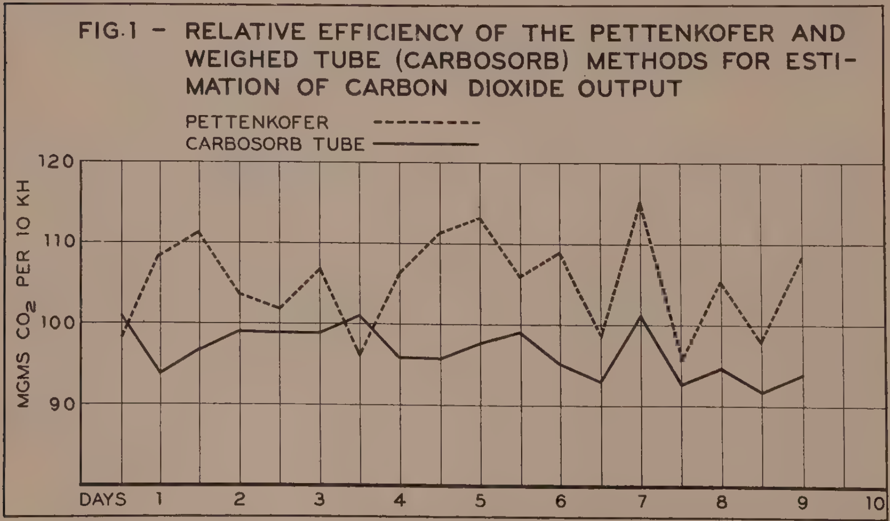

FIGURE 1. Relative carbon dioxide absorption by the weighed tube and Pettenkoffer methods for respiration measurements at 10° C.

relative efficiency of "Carbosorb" as compared with the Standard Pettenkofer method in which the carbon dioxide is absorbed by barium hydroxide. A small "Marco" pump was used to drive the air through the system.

The incoming air was passed through a large tube of soda lime and conditioned to a relative humidity of 75% by bubbling through a solution of 30% potassium hydroxide. After passing over the fruit the air was dried by means of two tubes of coarse- and fine-mesh calcium chloride respectively. A flask containing a weak solution of sodium hydroxide plus methyl orange was placed at the end of the train in order to detect improper absorption and to check the speed of the air flow (2 litres per hour). The entire apparatus is shown in Figure 2.

FIGURE 2. Apparatus for the estimation of carbon dioxide output of apples.

Estimations of the carbon dioxide output and oxygen uptake of fruit in the five-gallon containers were made by means of the Orsat apparatus.

RESULTS

Respiration

The measurement of the respiratory activity of fruit stored at low temperatures by means of gas analysis was considered to be unsatisfactory owing to the very slow rate of carbon dioxide output obtained under such conditions (see Figure 6). The first experiment, using the gas analysis method, was therefore carried out at 21° C.

The object of this experiment was to ascertain the effect of artificial atmospheres upon apples belonging to the Stark variety which had been stored in air at 3° C. for approximately four months. Samples of fruit, each weighing 2240 grams, were removed from storage and placed in containers the lids of which were sealed very thoroughly with a layer of vaseline 0.25 inch in thickness.

This method of obtaining a record of carbon dioxide is relatively crude when compared with the Pettenkofer or weighed tube method. Never-

theless it was felt that the use of such large samples, approximately 30 apples, would serve to minimize the error obtained by using single fruits. Care was taken to avoid upsetting the internal atmospheres, particularly the high carbon dioxide container, in which a negative pressure was developed at the time of analysis. In view of these reservations attention was given only to total carbon dioxide output and oxygen consumption over the period stated.

Four treatments were used and the changes in the atmospheres noted after 5 days. The containers were then thoroughly aerated and closed again for a further 4 days. Table 1 indicates the atmospheric changes found under these conditions.

Table 1.—Carbon dioxide output and oxygen uptake of Stark apples at 21° C. in different atmospheres (per cent decrease and increase in containers)

Treatment	In artificial atmosphere (5 days)		In air (4 days)		Respiratory quotient in air	
	CO_2 increase	O_2 decrease	CO_2 increase	O_2 decrease	Initial	Final
(1) 6.2% CO_2	14.3	11.0	10.7	7.9	1.66	1.08
(2) 53.5% CO_2	9.0	7.0	17.5	10.7	2.14	1.00
(3) 99.0% N_2	15.3	1.0	11.3	6.6	1.66	1.15
(4) Control in air	11.7	8.2	9.4	7.0	1.60	1.20

It will be seen that the total carbon dioxide output from fruits placed in high concentrations of carbon dioxide is less than that shown by the controls, but that upon removal to air the relationship is reversed as seen by the initial respiratory quotient in air of 2.14. This is followed by a sharp readjustment to an R. Q. of unity which would indicate an initial expulsion of carbon dioxide from the tissues.

On the other hand low carbon dioxide (6.2%) and nitrogen (99.0%) treatments are characterized by a greater increase in carbon dioxide output than the control which is also maintained upon removal to air. The oxygen consumption of these lots when removed to air differs in that the uptake of nitrogen-treated apples is lower than either the low carbon dioxide treatment or the controls. It may be further noted that the oxygen consumption of the high carbon dioxide treatment when removed to air is much in excess of the other lots.

Samples of McIntosh apples were also carried under similar conditions, but trouble was experienced with pressure differences when the containers were removed from cold storage to ordinary room temperatures. Nevertheless, both the Stark and McIntosh apples placed in nitrogen were characterized by a disappearance of the red pigmentation. This development, which to the writer's knowledge has not been reported before, is shown in Figure 3. The effect rather resembles soft scald when photographed, but is quite different in that the decolorized areas are almost white in appearance as distinguished from the sharply delimited light brown patches which are seen on scalded apples.

FIGURE 3. Loss of red pigmentation in senescent McIntosh apples stored in 100% nitrogen at 21° C.

The relative respiration rates of Golden Russet apples stored at 3° C. and 21° C., as determined by the weighed tube method, are shown in Figure 4, but the differences due to treatment with carbon dioxide are not

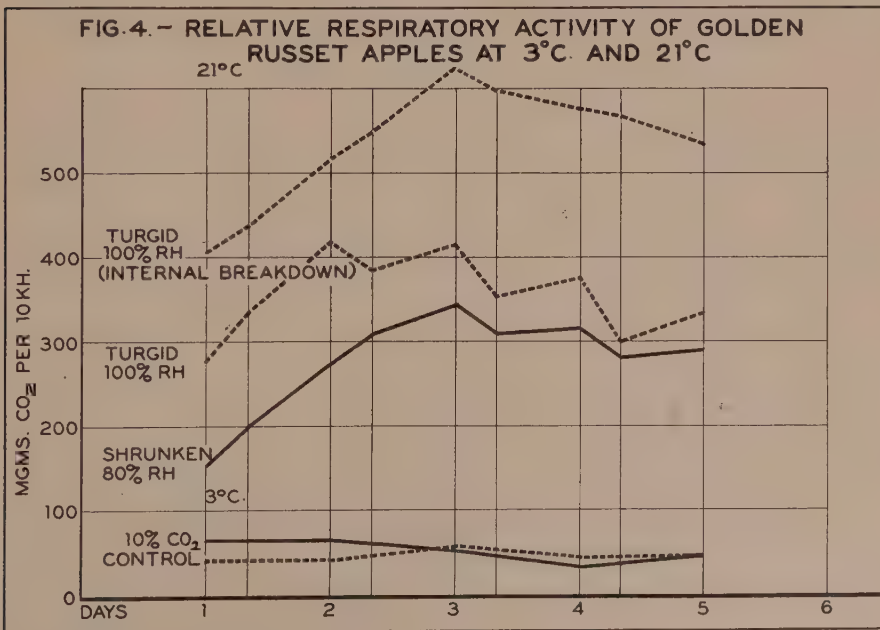

FIGURE 4. Relative respiratory activity of Golden Russet apples at 3° C. and 21° C.

clearly defined. It will be seen, however, that the respiratory ratio of fruits at 3° C. and 21° C. is in the order of 1 : 6 respectively. This ratio closely approximates the 1 : 5.35 ratio obtained by the writer (10) with Bramley's Seedling apples removed from 3° C. to 18° C. Furthermore, fruit stored in air with a relative humidity of 100% results in a higher rate of respiration over that shown by the controls in air at 80 to 85% R. H. when removed from 3° C. to 21° C. The great increase in carbon dioxide output of fruits affected by internal breakdown is also worthy of note.

In order to evaluate the size effect, not only in regard to carbon dioxide output but also to moisture loss, the three treatments, namely, shrunken controls, turgid controls, and those apples stored in 10% carbon dioxide, were duplicated using large and small fruits (three apples per sample). For determination of moisture loss the fruit was weighed both at the commencement and at the end of the experiment.

Table 2.—Total carbon dioxide and moisture loss of Golden Russet apples at 21° C.

Treatment	Weight of sample (in grams)	CO_2 loss (mgms. per kilo.)	Moisture loss (mgms. per kilo.)	Moisture/ CO_2
Shrunken (85% RH)	266.65	2503	8362	3.3
Shrunken (85% RH)	150.34	2649	9376	3.5
Turgid (100% RH)	256.84	3238	6262	1.9
Turgid (100% RH)	180.87	4600*	16497*	3.5
Turgid (10% CO_2)	210.23	3299	8525	2.6
Turgid (10% CO_2)	158.68	2912	9692	3.3
			Average	3.0

* Apples affected with internal breakdown.

Table 2 indicates that size is an important factor in the determination of relative rates of transpiration in that the ratio of surface area to bulk decreases with size increase, and thus the smaller fruits exhibit higher rates of transpiration than the larger fruits. The size effect is not so marked in relation to respiration in this test, and may be due to diffusion interference as brought about by the senescent condition of the internal tissues of the fruit. It is of interest to note that the ratio of the rates of respiration and transpiration in Golden Russet apples is approximately 1 : 3.

The first test with Golden Russet apples failed to clearly differentiate the carbon dioxide and high humidity effects. The experiment was therefore repeated, omitting the shrunken fruits; the two series were run in triplicate again using large and small apples. It will be seen from Figure 5 that the fruits stored under high humidity conditions respired more rapidly than those removed from 10% carbon dioxide (both previously stored at 3° C.); in addition, the moisture loss of the former sample was found to be 1.7 times greater than in the latter. Size relationships were again apparent in this experiment, but the results shown in Figure 5 are on an equivalent weight basis.

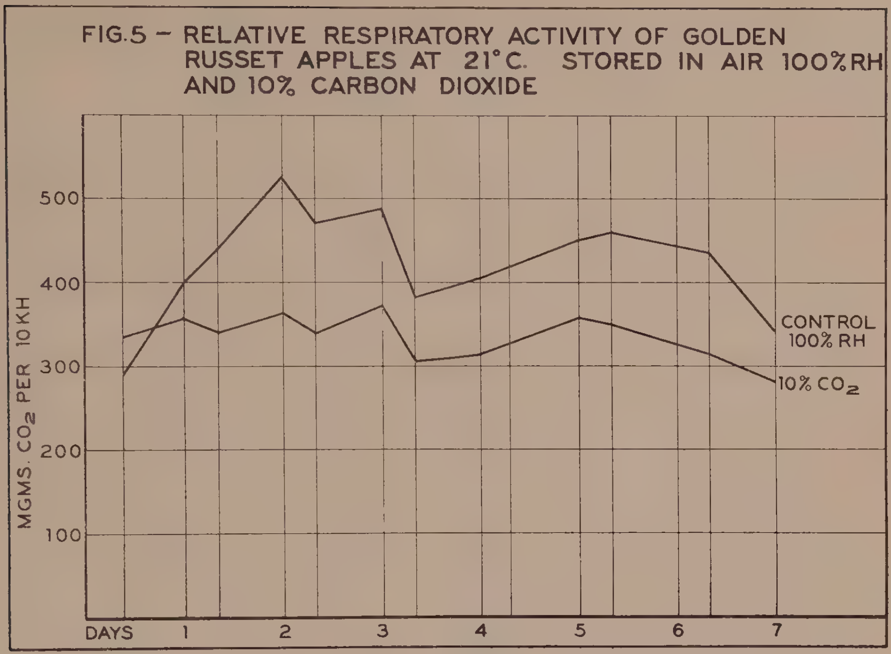

FIGURE 5. Relative respiratory activity of Golden Russet apples at 21° C. Stored in air 100% RH and 10% carbon dioxide.

Apples of the McIntosh variety stored in 5 and 10% carbon dioxide and in air at 3° C. were also transferred to 21° C. for respiration observations and were run in duplicate. Figure 6 shows that the carbon dioxide effect

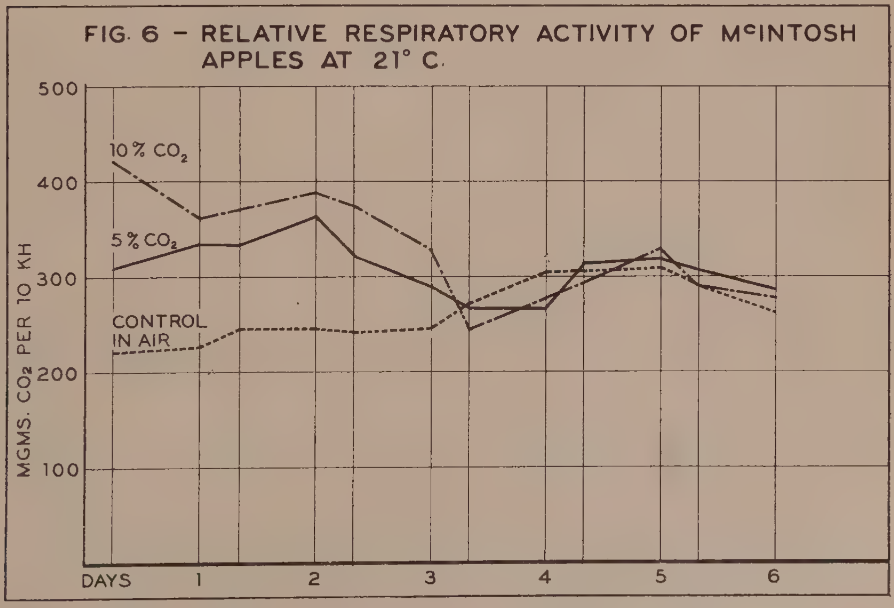

FIGURE 6. Relative respiratory activity of McIntosh apples at 21° C.

is similar to that found with Golden Russet apples except that the McIntosh fruits appear to lose the effect of the gas more rapidly as both the treated and untreated samples respire at the same rate after three days.

Biochemical Changes

Determinations were made on the hydrogen ion concentration and the total acidity (expressed as malic acid); carbohydrates were estimated on frozen macerated tissue. Moisture content was also determined, but the data obtained has been linked up with osmotic relationships of the treated fruits.

The juice was expressed from 10 apples in each treatment by means of an ordinary food grinder and a small hand press. Hydrogen ion concentrations were determined with a quinhydrone electrode apparatus, and the total acidity by titration against a standard solution of 0.1 N sodium hydroxide using phenolpthalein as the indicator.

Sugars were determined by the modified Munson and Walker (26) method which depends on the ratio of copper reduction to sugar oxidation in an alkaline solution. The major modification of the original method is the substitution of a citrate-carbonate reagent in the place of the Fehlings solution (Shaffer and Somogyi (29), Scoggan (30)). The first pH estimations were made on the treated fruit which was held in common storage, the results being shown in Table 3.

TABLE 3.—pH VALUES OF EXPRESSED JUICE OF APPLES HELD IN ARTIFICIAL ATMOSPHERES IN COMMON STORAGE, 3° C. TO 4.5° C.

Variety	Date examined	Control in air	O_2 2.5%	CO_2 2.5%	CO_2 5.0%	CO_2 10%
Russet	30/1/36	3.72	—	—	3.64	3.64
Russet	12/4/36	3.81	—	—	3.81	3.81
McIntosh	30/1/36	3.55	—	3.38	3.38	3.38
McIntosh	12/4/36	3.76	—	3.69	3.64	3.60
Cox Orange	30/1/36	3.64	3.81	3.59	3.64	3.55
Cox Orange	31/4/36	3.94	3.81	3.72	3.98*	3.81

* Apples affected with severe internal breakdown.

The results in Table 3 indicate quite clearly that the hydrogen ion concentration decreases as senesence proceeds, with the fall particularly marked in the McIntosh and Cox Orange apple varieties in which the activity during senescence is much more pronounced than in the Russet variety. With one exception the influence of carbon dioxide appears to be quite consistent, namely, a lower pH value than that obtained in the controls. It has been stated that the method of determination may cause a loss of carbon dioxide, but even if this were the case one might reasonably expect yet lower pH values than those obtained. There are no large differences in the values obtained between the effects of the various concentrations of carbon dioxide; those obtained in the last examination of Cox Orange apples are influenced by the development of incipient breakdown. The

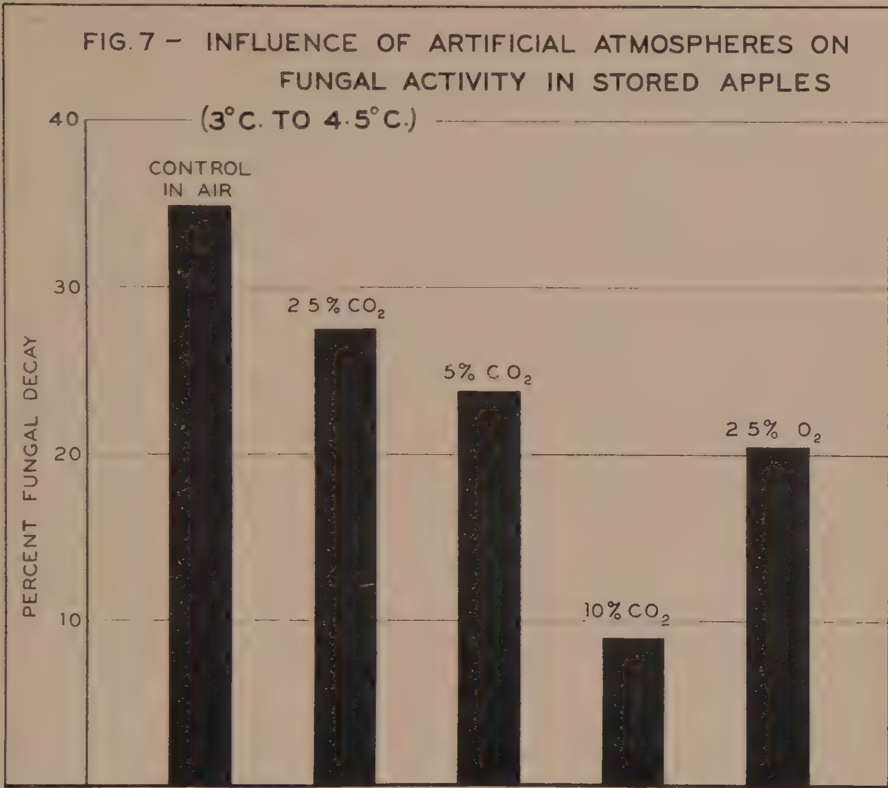

FIGURE 7. Influence of artificial atmospheres on fungal activity in stored apples (3° C. to 4.5° C.).

increase in alkalinity of the juice from the severely-broken-down fruits is particularly noteworthy.

It was decided to follow this investigation further, and at the commencement of the 1936 storage season samples of Gravenstein apples and Clapp Favorite pears were picked and immediately stored in containers with atmospheres of 100% carbon dioxide and 100% nitrogen for one week. The samples under the latter conditions were flushed with pure nitrogen every 24 hours until no carbon dioxide could be detected. Four temperatures were used: 0° C., 4.5° C., 10° C. and 18° C.

TABLE 4.—THE INFLUENCE OF ARTIFICIAL ATMOSPHERES UPON THE pH VALUES OF EXPRESSED JUICE OF APPLES AND PEARS AT DIFFERENT TEMPERATURES FOR ONE WEEK

Material	Treatment	Temperature			
		0° C.	4.5° C.	10° C.	18° C.
Apple	100% CO_2	3.14	3.17	3.24	3.28
Apple	100% N_2	3.10	3.05	3.17	3.09
Apple	Control in air	3.00	3.09	3.00	3.02
Pear	100% CO_2	4.17	4.41	4.37	4.55
Pear	100% N_2	3.90	4.10	3.90	4.09
Pear	Control in air	3.90	4.00	4.00	4.06

Table 4 shows that the carbon dioxide effects are reversed in relation to the results obtained in the previous experiment in that there is an increase in the alkalinity of the expressed juice which becomes more pronounced at higher temperatures. The greater change shown by the pears than the apples bears out the point that the former are able to absorb carbon dioxide to a greater extent than the latter fruits (13).

On the other hand, fruits in the absence of both oxygen and carbon dioxide show inconsistent effects, but the tendency appears to be in favour of a less acid reaction.

Estimations of total acidity were made in the course of the 1936–37 storage season on a series of treated fruits from common and 3° C. storage, save that the low oxygen and 2.5% carbon dioxide treatments were omitted, and a sample of Golden Russet apples stored in 100% relative humidity was added. The results are shown in Table 5.

TABLE 5.—PER CENT MALIC ACID IN APPLES STORED IN ARTIFICIAL ATMOSPHERE IN COMMON STORAGE (C.S.), 3° C. TO 4.5° C. FOR FIVE MONTHS

Variety	Temperature	Control in air 85% RH	Air 100% RH	CO_2 5%	CO_2 10%
Russet	C.S.	0.235	0.257	0.281	0.300
Russet	3° C.	0.372	0.359	0.370	0.360
McIntosh	C.S.	0.216	—	0.267	0.293
McIntosh	3° C.	0.317	—	0.317	0.359
Cox Orange	C.S.	0.270	—	0.289	0.320
Cox Orange	3° C.	0.349	—	0.331*	0.312†

Apples slightly* and severely† affected with internal breakdown.

Under the higher temperature conditions it will be noted in Table 5 that the carbon dioxide has retarded the rate of acid consumptiom, but that at 3° C. the differences are inconsistent although the acid content is higher than that found under common storage conditions. There is also a decrease in total acidity as well as actual acidity in fruits affected with breakdown.

With regard to the effect of humidity it should be pointed out that the fruits stored at the higher temperatures in relative humidities of 85 and 100% were very shrunken and firm respectively, whilst at the lower temperatures the degree of firmness differed very slightly in the corresponding samples. This variation in moisture loss may account for the conflicting values obtained, but this point requires further investigation.

TABLE 6.—PERCENTAGES OF TOTAL, REDUCING AND NON-REDUCING SUGARS IN COX ORANGE APPLES STORED FOR 3 MONTHS IN ARTIFICIAL ATMOSPHERES AT 3° C. TO 4.5° C.

Treatment	Total	Reducing	Sucrose
2.5% O_2	10.40	7.73	3.22
2.5% CO_2	11.73	7.56	4.79
10.0% CO_2	10.50	7.32	3.73
Control in air	12.53	7.43	5.58

Carbohydrate estimations were confined to the Cox Orange apples. It must be pointed out that the figures shown in Table 6 are purely indicative as the data are insufficient to

warrant definite conclusions being drawn. It may be seen, however, that the low oxygen concentration has apparently accelerated the loss of sucrose as found by Fidler (11), and a similar effect but less marked may be seen in the sucrose value for the 10% carbon dioxide treatment. The control in air is characterized by the least loss in total sugars of all treatments.

Observations were made on the colour changes occurring in the stored fruits and it was seen that all the carbon dioxide treatments and also the low oxygen retarded the yellowing of the ground colour on McIntosh and Cox Orange apples.

Osmotic and Permeability Relationships

The plasmolyticum used in the determination of osmotic values and of permeability was calcium chloride, as it has been shown that this solution is unable to enter plant cells. Furthermore, the solution will last several months according to Levitt and Scarth (23). The chief objection to the use of sucrose is that of nicro-organic development and this was observed in the course of these investigations. Osmotic values were estimated to within 0.01 M and a series of solution were made up from 0.1M to 1M calcium chloride.

The osmotic pressures in atmospheres were calculated from the freezing points given in the International Critical Tables according to the equation

$$OP = 12.06 - \Delta 0.021^2$$

in which OP = osmotic pressure and Δ = corrected depression of the freezing point. This equation was also used in connection with the cryoscopic determinations of osmotic pressures.

Neutral red 5 p.p.m. was adopted as the staining medium throughout these cellular studies; the cell walls remain unstained and the dead cells are easily distinguishable by the purplish granulated appearance of the protoplasm. A minimum of ten sections were used for the determination of incipient plasmolysis, this point being reached when over 50% of the cells showed this characteristic.

Cryoscopic determinations were made by means of a Hortvet cryoscope upon juice expressed from freshly thawed macerated apple tissue. Corrections were made for the true depression of freezing point using the tables of Harris and Gortner (15).

Estimations of moisture content were made on 20-gram samples of freshly thawed tissue utilizing two methods: (1) 100° C. for 24 hours, and (2) 50° C. in vacuo for 48 and 72 hours. The figures obtained for the 48-hour period in the second method have been omitted, as it was found that the moisture estimate after 72 hours drying did not exceed by more than 0.1% that obtained after 48 hours.

In Table 7 it will be seen that the pressure in pounds required to break the apple tissue with a penetrometer is included, and also the percentage of total solids as calculated from the refractive index of the juice. An Abbé prism refractometer was used to obtain the refractive index of the juice, and the corresponding percentage of total solids was derived from the International Critical Tables.

TABLE 7.—OSMOTIC PRESSURE, MOISTURE CONTENT, TISSUE RESISTANCE AND THE PERCENT TOTAL SOLIDS (EXPRESSED JUICE) OF APPLES STORED IN DIFFERENT ATMOSPHERES IN COMMON STORAGE FOR THREE MONTHS AT 3° C. TO 4.5° C.

Variety	Treatment	Percentage moisture fresh weight		Osmotic pressure in atmospheres		Pressure in lbs. (penetrometer)	Per cent solids
		50° C. in vacuo 72 hr.	100° C. 24 hr.	Cryoscopic method	Plasmolytic method		
Golden Russet	Controls	80.85	80.75	24.28	28.02	20.6	16.0
	5% CO_2	81.88	84.31	23.50	25.23	25.0	16.0
	10% CO_2	82.14	85.14	22.36	23.89	23.7	15.6
Cox Orange	Controls	82.49	84.35	22.42	—	15.5	15.2
	2 5% O_2	82.96	85.48	22.72	—	20.5	14.4
	2.5% CO_2	83.10	85.85	19.37	—	16.5	13.8
	5.0% CO_2	82.98	84.76	21.53	—	16.8	13.2
	10.0% CO_2	82.80	85.26	21.88	—	17.3	13.4
McIntosh	Controls	86.67	88.02	15.34	17.40	14.4	11.6
	2.5% CO_2	86.44	88.83	15.94	—	13.1	10.7
	5.0% CO_2	86.46	88.25	16.57	16.77	12.1	11.0
	10.0% CO_2	86.66	89.02	15.73	16.77	12.2	10.7

With the exception of the Golden Russet controls it will be seen that drying at 100° C. for 24 hours gives a consistently higher figure for moisture content than that at 50° C. for 72 hours (Table 7).

There is a general correlation between moisture content, osmotic values, and percentage of total solids from the varietal standpoint. It must be pointed out that the relative humidity was higher in the treated samples than it was in the control lots, and thus the latter are consistently lower in water content and higher in the observed osmotic values. It was found later that Golden Russet apples which had been stored in air, one lot in 100% relative humidity, and another in 85%, showed osmotic pressures of 21.88 and 23.22 atmospheres respectively.

The difference between the osmotic pressures as obtained by the two methods is in keeping with the findings of other workers (2, 9).

The pressure in pounds required to puncture the sub-epidermal tissues of the fruit has been included in order to show in particular the remarkably firm condition of the Cox Orange fruits stored in 2.5% oxygen in relation to the high values obtained for the osmotic pressure, water content and total solids. It would appear, therefore, that low oxygen conditions have been instrumental in retarding the loss of cell wall materials, possibly pectic constituents.

The effect of carbon dioxide would seem to tend toward decreasing the osmotic pressure. The very low value obtained in the Cox Orange apples treated with 2.5% carbon dioxide is attributed to the onset of internal breakdown. A further attempt was made to elucidate the treatment effects by calculating the osmotic values on the basis of the control values for moisture.

The corrected values shown above again indicate that increased carbon dioxide results in a lower osmotic value relative to the controls in air but this point requires further investigation.

Determinations were first made on the permeability of apple cells to various solutes, neutral red being used as the staining medium. The

TABLE 8.—OSMOTIC PRESSURES OF APPLE CELLS (CORRECTED FOR MOISTURE) STORED IN DIFFERENT ATMOSPHERES FOR THREE MONTHS AT 3° C. TO 4.5° C.

Variety	Control in air	2.5% O_2	2.5% CO_2	5% CO_2	10% CO_2
Golden Russet	24.38	—	—	23.10	21.20
Cox Orange	22.42	22.6	19.20	21.75	21.75
McIntosh	15.34	—	16.05	16.65	15.75

following non-electrolytes were included: glycol, thiourea, urea, glycerol, and sucrose; also one electrolyte, namely, potassium nitrate. Sections were placed in twice isotonic solutions of the above substances and examined at 5-minute intervals for signs of deplasmolysis. It was found that the solutions of glycol and urea caused no plasmolysis, and there was only slight plasmolysis of the cells for 5 minutes with thiourea and glycerol. On the other hand, both sucrose and potassium nitrate produced strong plasmolysis in 5 minutes; the latter solute, however, was more powerful in its action, but neither of them showed signs of deplasmolysis at the end of 45 minutes after which time all the cells were dead. With the exception of thiourea it may therefore be concluded that the more polar the compound is the more impenetrable does the cell become to the same.

During the course of the above tests vacuolization was noted in carbon-dioxide-treated cells placed in thiourea and sucrose as shown in Figure 8. It is of interest to note that difficulty was experienced in obtaining these photographs as the vacuoles disappeared after a time. A peculiar characteristic which was observed in cells plasmolysed in a normal sucrose solution is shown in Figure 9. It would almost seem that there are two distinct membranes on the edge of the large vacuole in the centre cell; moreover, when the cell was observed prior to being photographed, the second or outer membrane was more pronounced and at a greater distance from the vacuole. There is the possibility, however, that in the process of plasmolysis a portion of the interior of the cell wall was drawn away with the protoplasm.

The relative permeability of cells to water in the case of treated Golden Russet apples was determined by measuring the time required for the cells to deplasmolyse. This was done by plasmolysing the cells in a twice isotonic solution of calcium chloride. They were left in this solution for about 20 minutes and then transferred to a half isotonic solution of the same salt for deplasmolysis. The average rate of permeability for 20 cells is shown in Table 9.

TABLE 9.—THE INFLUENCE OF CARBON DIOXIDE IN THE PERMEABILITY OF APPLE CELLS (3 MONTHS IN COMMON STORAGE, 3° C. to 4.5° C.) AVERAGE OF 20 CELLS

Treatment	Time required to reach incipient plasmolysis (min.)
Control in air	8
5% CO_2	6
10% CO_2	5

The figures given clearly indicate the increase in permeability of apple cells as a result of carbon dioxide treatment. This study was confined to the Golden Russet variety owing to sectioning difficulties with the other fruits. Nevertheless, in order to further substantiate these findings,

other studies were undertaken at the commencement of the next season with freshly-picked fruits. Samples of Gravenstein apples and Clapp Favourite pears were placed in containers, the atmospheres in which were as follows: 100% carbon dioxide, 100% nitrogen, and a control in air. Four temperatures were used: 0° C., 4.5° C., 10° C. and 18° C. A similar procedure to that described in the previous experiment was used.

Table 10.—The influence of carbon dioxide and nitrogen on the permeability of the cells of apple and pear fruits stored for one week at °0 C., 4.5° C., 10° C. and 18° C.

Fruit	Temperature, degrees Centigrade	Time required to reach incipient plasmolysis (min.)		
		Control in air	100% CO_2	100% N_2
Pear	0	13.4	6.8	14.9
	4.5	7.7	9.0	12.0
	10	16.6	10.9	12.0
	18	12.5	12.0	7.0
Apple	10	15.0	7.0	20.0
Average for pears (all temperatures)		16.7	12.9	14.8

The results shown in Table 10 again indicate that carbon dioxide increases the permeability of cells to water; the results, however, with tissues stored in the absence of oxygen are not consistent. Temperature effects are not well defined although there is a consistent decrease in the permeability of the carbon dioxide series as the temperature is raised.

The viscosity of the apple and pear cells was tested by placing blocks of tissue in isotonic solutions and centrifuging them; sections were then taken from the tissue and examined as to the position of the starch grains. It was found that starch grains in the Gravenstein apple were thrown down too quickly (2 minutes) for timing purposes. The grains in the Clapp Favourite pears moved more slowly; accordingly, four samples of treated pears were tested as above; namely, in air, 100% carbon dioxide, and 100% nitrogen, each at 4.5° C., and 100% carbon dioxide at 18° C. This series was centrifuged for 5-minute intervals, in which it was observed that no movement of starch grains had taken place in the control and in the 100% nitrogen-treated apples, whereas in the carbon dioxide series there was a heavy accumulation of grains at the ends of the cells of tissues treated at 4.5° C., but only a slight movement had taken place in those tissues treated at 18° C. The temperature influence may be accounted for by the increased solubility of carbon dioxide at lower temperatures.

The permeability of apple tissues as measured by the diffusion of electrolytes into solutions of distilled water was studied in order to verify the foregoing data if possible. This was accomplished by placing discs of apple tissue in distilled water of a known electrical conductivity and measuring the decrease in resistance at 24-hour intervals.

Preliminary readings were made on uniform cylinders of tissue from apples which had been treated; the tissues from the 2.5 and 5% carbon dioxide treatments were affected with physiological breakdown and the increased leaching of ions from these cells is clearly evident (Table 11).

TABLE 11.—ELECTRICAL CONDUCTIVITY OF LEACHINGS FROM COX ORANGE APPLE TISSUES STORED IN ARTIFICIAL ATMOSPHERES (EXPRESSED AS RECIPROCAL OHMS $\times 10^5$ AFTER 24 HOURS)

Variety	Control in air	Treatment			
		2.5% O_2	2.5% CO_2	5% CO_2	10% CO_2
Cox Orange	600	540	680*	666*	600

* Apples affected with internal breakdown.

The figures do not indicate a carbon dioxide effect when the controls and 10% carbon dioxide are compared, but the low permeability of the tissues stored in 2.5% oxygen is striking, also that obtaining in diseased tissue.

In view of the above results another experiment with Golden Russet apple tissue was set up in triplicate. Cylinders of tissue were removed from the apples by means of a cork borer (0.65 cm. bore) and cut up into discs 0.25 cm. thick. Discs of each sample were then placed in 50 cc. of distilled water, the conductivity of which was determined and found to be uniform. Three readings were made at 24-hour intervals, the fourth being discarded on account of mould development.

TABLE 12.—ELECTRICAL CONDUCTIVITY OF LEACHINGS FROM GOLDEN RUSSET APPLE TISSUE STORED IN ARTIFICIAL ATMOSPHERES FOR FOUR MONTHS (EXPRESSED AS RECIPROCAL OHMS $\times 10^5$)

Variety	Time in hours	Serial number	Treatment		
			Control in air	5% CO_2	10% CO_2
Golden Russet	24	1	125	113	126
	24	2	126	113	126
	24	3	Lost	113	126
	48	1	145	156	178
	48	2	145	154	180
	48	3	—	153	180
	96	1	166	178	200
	96	2	166	180	200
	96	3	—	180	200

The permeability as shown in Table 12 is apparently increased by the carbon dioxide effect when the later conductivity measurements are compared. The first reading after 24 hours may be affected by the initial wounding of the tissues because thereafter the conductivity of leachings from sample to sample is quite consistent.

Fungal Activity

Two examinations of the stored fruits were made in order to determine the wastage due to fungal decay. The total decay for all varieties under each treatment is shown in Figure 7, the inhibitory effect of the artificial atmospheres employed being clearly demonstrated, particularly in 10% carbon dioxide. Examination of the data reveals, however, that the retarding influence of carbon dioxide and low oxygen is more marked in the early stages of storage as shown in Table 13.

TABLE 13.—PERCENTAGE OF FUNGAL DEVELOPMENT ON APPLES STORED IN DIFFERENT ATMOSPHERES FOR THREE MONTHS AT 3° C. TO 4.5° C.

Variety	Treatment	Examined 25/1/35	Examined 1/4/36	Ratio
Cox Orange (1)	Control in air	18.0	31.5	1.72
Cox Orange (2)	Control in air	16.0	60.0	3.74
McIntosh	Control in air	42.0	63.6	1.54
Cox Orange (1)	10% CO_2	2.0	26.3	13.50
Cox Orange (2)	10% CO_2	2.0	17.4	8.20
McIntosh	10% CO_2	0.0	20.0	20.00
Cox Orange (1)	2.5% O_2	10.0	24.0	2.40
Cox Orange (2)	2.5% O_2	4.0	44.0	11.00

In order to determine the influence of these same atmospheres upon the pure cultures of *Penicillium expansum* (the organism almost entirely responsible for the wastage observed in these experiments), isolations were made from decayed fruits and transferred to slants of sterile media (potato dextrose agar). After about two weeks the slants were examined and transfers were made from the pure cultures to petri plates (three for each treatment); these were immediately placed in the storage containers and the lids of the dishes removed. The control containers were covered with cheese cloth in order to eliminate contamination from the outside air as far as possible without interfering with the atmospheric conditions.

First of all, however, preliminary tests were made with sterile plates which were placed in the various atmospheres for 6 days in order to ascertain the degree of contamination to be found under such conditions. It is clear from an examination of Figure 10 that the infectivity of spores is considerably reduced by carbon dioxide and to a lesser extent by low oxygen. The influence of these same atmospheres on pure cultures of *Penicillium expansum* for a period of 12 days is shown in Figure 11. The following observations were made.

The control in air was characterized by heavier sporulation than was seen in all the other treatments, but growth was much the same as in 2.5 and 5.0% carbon dioxide; it is possible, therefore, that in the case of the controls, growth was retarded by the sporulating activities of the colony.

The colonies in 10% carbon dioxide and 2.5% oxygen showed less growth than in all other treatments and also less sporulation. In addition, the colony in 2.5% oxygen was peculiar in that aerial white mycelium developed in contrast to the depressed appearance of the other colonies.

Observations were also made after the plates were removed to room

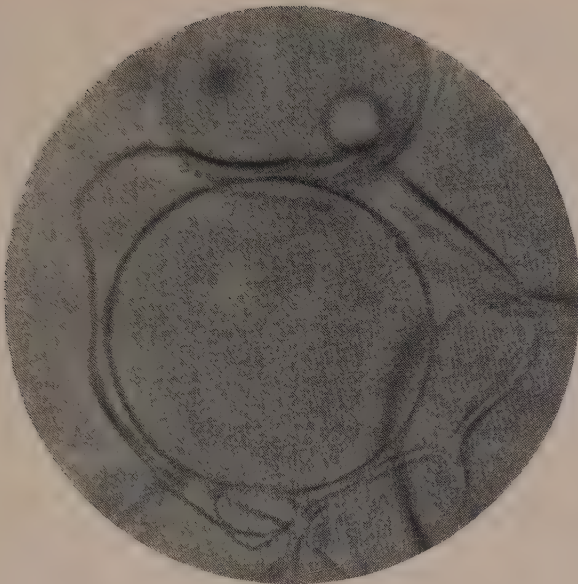

FIGURE 8. Plasmolyzed apple cells showing vacuolization (stained with neutral red).

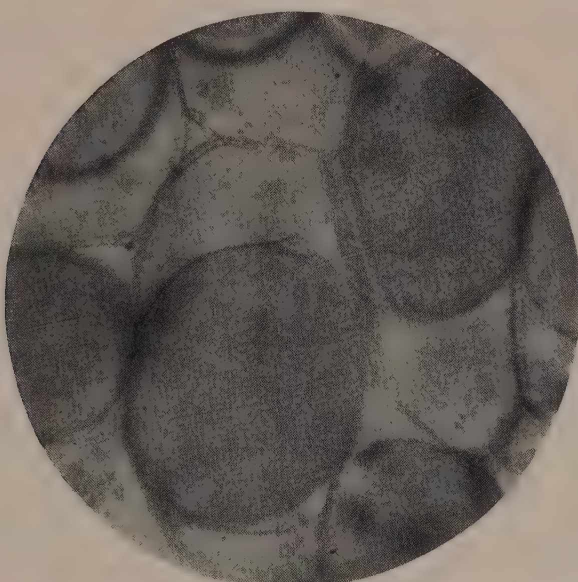

FIGURE 9. Plasmolyzed apple cells showing "double membrane" effect (stained with neutral red).

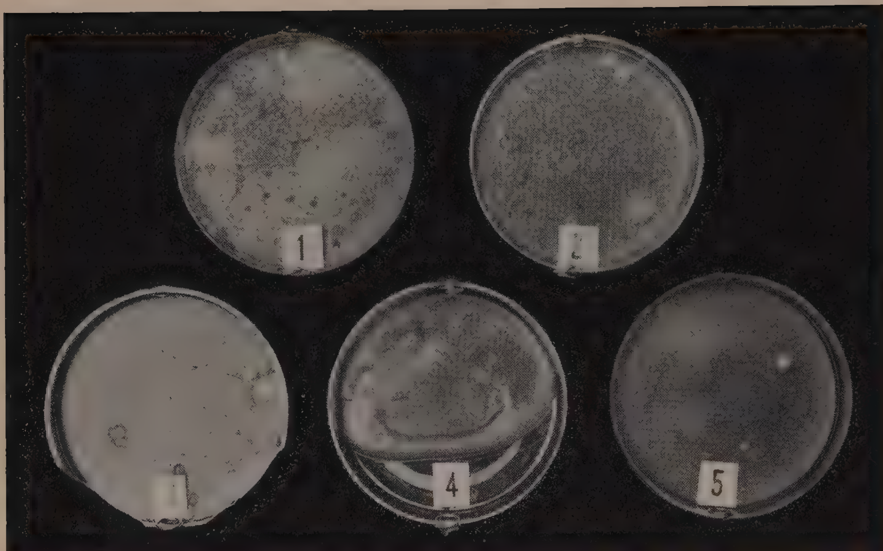

FIGURE 10. The influence of artificial atmospheres upon the growth of fungal spores on sterile media (Petri plates placed in apple storage containers). 1. Stored in air; 2. 2.5% O_2; 3. 2.5% CO_2; 4. 5.0% CO_2; 5. 10.0% CO_2.

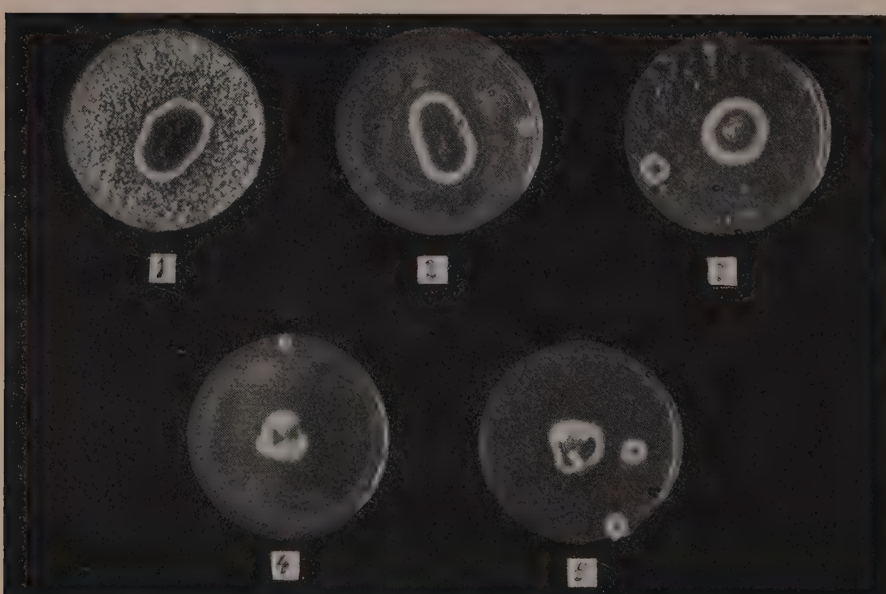

FIGURE 11. The influence of artificial atmospheres upon the growth of colonies of *Penicillium expansum*. 1. Stored in air; 2. 2.5% CO_2; 3. 5.0% CO_2; 4. 10.0% CO_2; 5. 2.5% O_2.

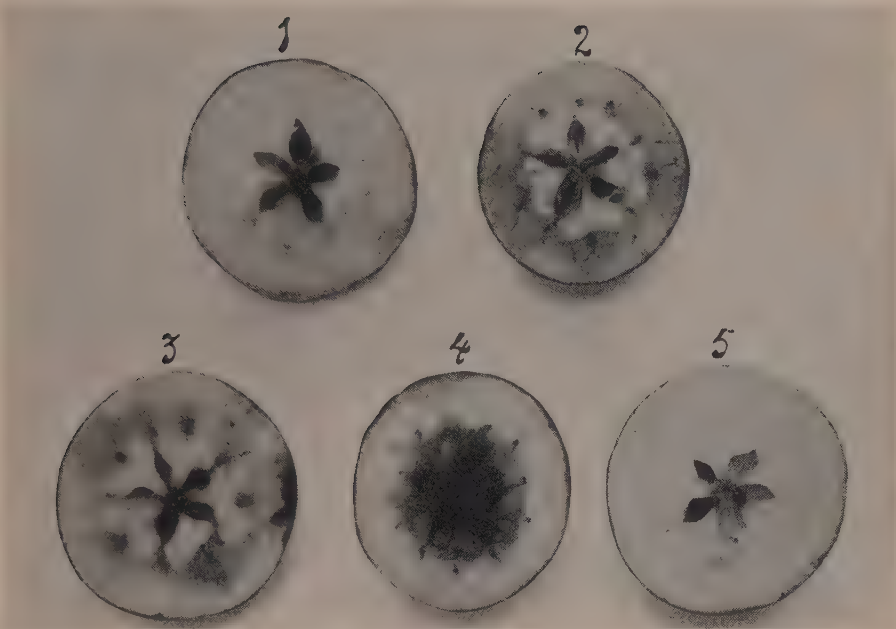

FIGURE 12. Physiological breakdown of Cox Orange apples stored in artificial atmospheres at 3° C. to 4.5° C. 1. Stored in air; 2. 2.5% CO_2; 3. 5.0% CO_2; 4. 10.0% CO_2; 5. 2.5% O_2.

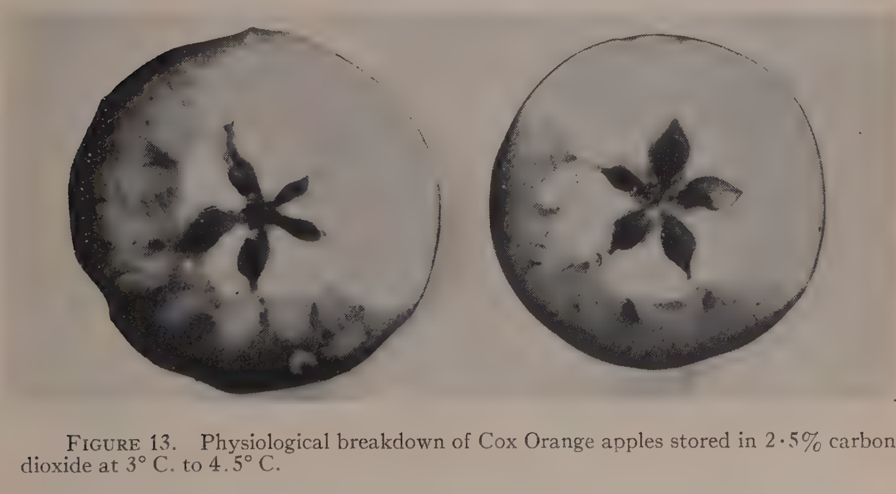

FIGURE 13. Physiological breakdown of Cox Orange apples stored in 2·5% carbon dioxide at 3° C. to 4.5° C.

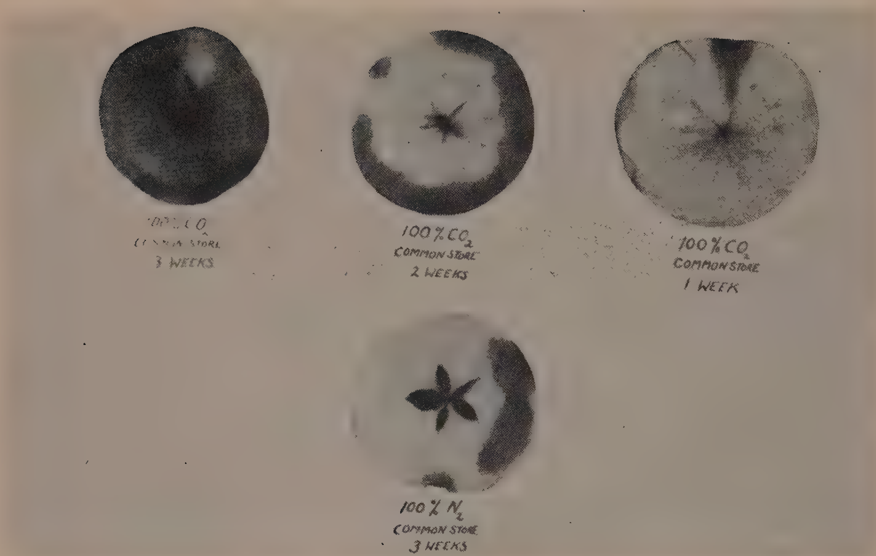

FIGURE 14. Physiological breakdown of McIntosh apples stored in 100% carbon dioxide and 100% nitrogen.

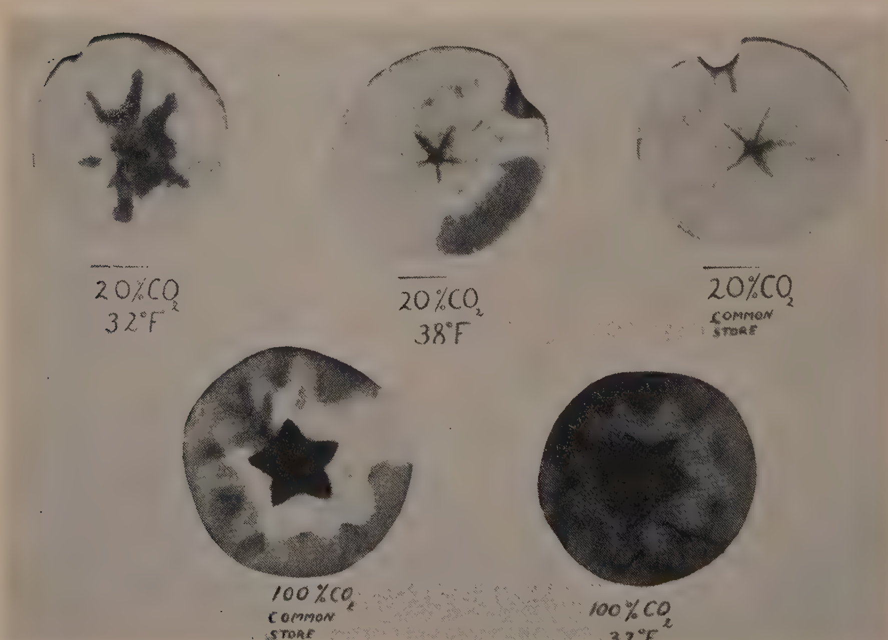

FIGURE 15. The influence of temperature on the breakdown of McIntosh apples stored in 20% carbon dioxide.

temperatures in air and it was seen that the control rapidly increased growth and sporulating activities as did the colony stored in 2.5% oxygen. On the other hand, the carbon dioxide treated cultures showed a slow reaction to environment, particularly that in 10% carbon dioxide, which might possibly indicate that the media had become toxic as a result of the atmospheric conditions during treatment.

Physiological Disorders

McIntosh apples stored in 10% carbon dioxide possessed a very pronounced alcoholic flavour, the samples in 5% concentration were slightly off flavour but those in 2.5% concentration remained in excellent condition. The low average temperature (3° C.) during the latter part of the storage season may account for the flavour developed in the sample stored in 5% carbon dioxide. No wastage due to functional disorders was observed with this variety with the exception of a slight corticle flush which appeared in the controls in air. Golden Russet apples remained in perfection condition in both 5 and 10% carbon dioxide concentrations until the sixth month when it was observed that a mottled type of scald had made its appearance. In the 5% carbon dioxide treatment, 77% of the apples were scalded, whereas in the 10% series only 31% were affected. The necessity of wrapping fruits of this variety in oiled paper for storage under such conditions at once becomes apparent. The controls in air were only characterized by heavy shrinkage. Duplicate samples of all treatments in the Cox Orange series were carried in storage. Table 14 shows the results obtained.

TABLE 14.—FUNCTIONAL DISORDERS AND FLAVOUR OF COX ORANGE APPLES STORED IN ARTIFICIAL ATMOSPHERES IN COMMON STORAGE (3° C. TO 4.5° C.)

Serial number	Per cent CO_2	Per cent O_2	Per cent breakdown Examined 25/1/36	Per cent breakdown Examined 13/4/36	Flavour 25/1/36
14	0.0*	2.5	—	—	Slightly bitter
15	0.0*	2.5	—	—	Slightly bitter
12	2.5	18.5	20.0	21.0	Good
13	2.5	18.5	10.0	50.0	Good
8	5.0	16.0	22.0 (heavy)	72.7	Good
9	5.0	16.0	2.0	100.0	Good
10	10.0	11.0	—	47.4	Slightly alcoholic
11	10.0	11.0	—	35.5	Slightly alcoholic
Control	—	—	—	—	Mealy (No flavour)

* Determined.

Table 14 indicates that the onset of functional disorders is induced by increased carbon dioxide concentrations, and that apart from deleterious effects upon the flavour the low oxygen treatment and the controls constituted the best treatments (see Figure 12). The low oxygen concentration, furthermore, is characterised by very hard firm fruits which corresponds with observations made by the writer on pears treated in a

similar manner. The relatively high percentage of breakdown in the 5% carbon dioxide series is particularly striking. The appearance of the breakdown as found in each treatment is shown in Figure 12 and it would seem that the physiological effects are more or less specific. In Figure 13 it will be seen that the disorder in apples stored in 2.5% carbon dioxide is confined to the peripheral tissues, a characteristic of mealy breakdown. Furthermore, Table 14 shows that breakdown in the first examination was confined to the 2.5% and 5% series. The latter samples were not so markedly affected in the peripheral areas but rather more so in the vascular areas. The apples stored in 10% carbon dioxide are in contrast to the above treatments in that disintegration of the tissues is more or less limited to the core area including the 10 main vascular bundles.

Careful comparison with the illustrations of mealy breakdown and brown heart as shown in the publication by Plagge and his associates (28) would indicate that the 2.5 and 5% treatments are types of mealy breakdown, while 10% carbon dioxide has induced brown heart.

Observations on the effects of atmospheres devoid of oxygen upon McIntosh and Stark apples at room temperature after storage at 3° C. for 4 months showed that both varieties developed breakdown which resembled soggy breakdown. This type has been previously noted at the Kentville Experimental Station in McIntosh apples exposed to 100% nitrogen at 0° C. for 3 weeks after 2 months storage, but did not appear until a month later in common storage (see Figure 14). The disorder usually arises in the corticle region of the apple as scattered light brown patches. At first these are well defined, but they gradually merge into a band-like area of soft tissue, approximately 0.5 cm. from the epidermis, as seen when an affected apple is halved at right angles to the core line. This band of dead tissue may or may not completely surround the cortex, but in the advanced stages of development the healthy sub-epidermal tissue gradually breaks down, which is followed by external browning of the apple skin and final disintegration of the entire fruit. As will be noted from the above table, low oxygen conditions produced a bitter flavour in the fruit and which was more marked in apples stored in pure nitrogen immediately after harvesting for a period of one week.

Finally the effects of high concentrations of carbon dioxide upon McIntosh apples are shown in Figures 14, 15; it was noted that very pronounced alcoholic flavours developed in the fruits and that the degree of tolerance toward the gas was less at low temperatures.

DISCUSSION

These investigations have been directed toward a consideration of the physiological effects of artificial atmospheres upon the cellular activities of senescent fruits. It has been shown that the total carbon dioxide output of apples is depressed and stimulated by high (53.5%) and low (6.2%) concentrations of carbon dioxide, respectively, during a period of 5 days. It is necessary, however, to bear in mind the findings of Kidd, West and Kidd (21) who have shown that prolonged storage in 5 and 10% carbon dioxide depresses the respiratory activity of fruits. The development of alcoholic flavours under conditions of high carbon dioxide would point to a stimulation of the anaerobic fermentation system in the cell.

The increase in carbon dioxide output of fruits which were removed from air to pure nitrogen may be due in part to the expulsion of carbon dioxide within the tissues as suggested by Gustafson (14) and to the protective role of aerobiosis in relation to anaerobiosis as postulated by Blackman (3). The corresponding increase in carbon dioxide evolution from apples when removed from high concentrations of the same gas to air also indicates a rapid expulsion of carbon dioxide and possibly the temporary nature of the narcotic influence exerted by carbon dioxide (12, 33). Further the oxygen uptake of the nitrogen-treated fruits when returned to air was lower than that which obtained in those stored in air in spite of the greater carbon dioxide output of the former. It would appear, therefore, that anaerobic processes were still functioning in the treated fruits when stored in air. No evidence was obtained however regarding the extinction point (E) of fermentation in these fruits (31).

The respiratory activity of fruits was determined in air at 3° C. and at 21° C.; the apples used had been stored in 5 and 10% carbon dioxide for approximately 4 months. It was observed that the treated apples evolved a greater amount of carbon dioxide than the controls upon removal to 21° C. The higher value may be due first to the higher concentration of respirable substrate, and second to the disappearance of accumulated carbon dioxide within the tissues. The first explanation is of interest when it is remembered that the Golden Russet apples stored in a relative humidity of 100% in air evolved as much or more carbon dioxide than did the treated fruits. The importance of moisture relationships at once becomes apparent, and in this connection it was found that apples of the same variety lost approximately three times as much moisture as carbon dioxide. In contrast Wardlaw and Leonard (37) report that tropical fruits lose 10 times as much water as carbon dioxide. It was found that the loss of these constituents from apples varied inversely as the size.

A marked deceleration in the rate of loss of total acids in fruits stored in carbon dioxide was observed. Magness and Diehl (24) found that acid loss increased in Delicious and Winesap apples stored in carbon dioxide. Kidd, West and Kidd (21) on the other hand showed that the acid loss was retarded in Bramley's Seedling apples stored in 10% carbon dioxide.

Juice from apples stored in low concentrations of carbon dioxide for 3 months was characterized by a lower pH value than that obtained with juice from air-stored fruits; a higher pH value was obtained, however, when apples were subjected to 100% carbon dioxide for one week. Nevertheless, Thornton (35) states that carbon dioxide in the presence of oxygen decreases the hydrogen ion concentration in a wide range of plant tissue including the McIntosh apple, both in high and low concentrations of carbon dioxide at 25° C. On the other hand, potato tubers treated with 100% carbon dioxide increased in acidity. No significant changes were found in the pH values of cherries, plums and peaches which had been treated with 50% carbon dioxide according to Miller and Dowd (25). Jacobs (17) has shown that carbon dioxide has a specific effect as an undissociated gas producing lethal effects at an increased hydrogen ion concentration.

Pure nitrogen and low oxygen treatments had little effect upon the hydrogen ion concentration of apple juice although there was a slight tendency toward a less acid reaction. Fidler (11) has shown that rate of acid

loss in apples and oranges remains unaffected by the absence of oxygen. He suggests that acid loss is not due to oxidation to carbon dioxide but rather that it undergoes reduction with the evolution of oxygen which could in turn oxidize some intermediate product of carbohydrate metabolism.

Loss of carbohydrates as total sugars appeared to be increased by storage in both 10% carbon dioxide and 2.5% oxygen; this was more marked in the sucrose fraction, particularly under the latter conditions. These findings are in accord with those of Kidd, West and Kidd (21) in regard to the carbon dioxide effect, and with those of Fidler (11) who found that sucrose is lost more rapidly under anaerobic conditions.

The data obtained on osmotic values were complicated by the presence of lower relative humidities in the control containers than in those containing artificial atmospheres. Nevertheless the carbon dioxide treatments appeared to reduce, and the low oxygen to increase, the osmotic pressure in apple cells relative to the controls in air. There was found to be a varietal correlation between osmotic pressure, water content and the percentage total solids in the juice. That there is a wide variation in the osmotic values of cells in different varieties of apples is supported by the work of Chandler (7). Walter (36) lists the following fruits together with the respective osmotic pressures in atmospheres: apples, 23.81; grapes, 28.0; tomatoes, 8.79; and citrus fruits, 14.0.

It has been shown that carbon dioxide increases the permeability of the cells both to water and to leachings. Furthermore, apolar compounds such as urea, penetrate into the cell, while calcium chloride and potassium nitrate, which are strongly polar, failed to enter. These findings are in line with the work of Jacobs (19) who observed that the penetrability of solutes is a function of lipoid solubility supports the hypothesis of Overton (27) that the plasma membrane of the cells is composed largely of water with a differential lipoid phase. Heilbrunn (16) points out that carbon dioxide is frequently used as an anaesthetic in physiological studies and thus may cause dissolution of the lipoid phase (a characteristic of anaesthetics). This observation is borne out by the findings of Jacobs (18) who noted that with *Spirogyra* short exposures of carbon dioxide brought about a liquefaction of the protoplasm while long exposures caused coagulation. In studies on the carbon dioxide narcosis of *Nitella*, Fox (12) observed an increase in the permeability of cells, vacuolization and cyclosis or stoppage of protoplasmic streaming which he suggests is due to the gelation of the colloidal matrix as seen by the jerky motions of the granules (unlike Brownian movement) caused by the kinoplasm (or streaming plasm) when the granules become fixed in the gel.

No consistent differences between the fruit held in low oxygen and in air were noted in relation to water permeability.

Several investigations have shown that carbon dioxide produces an inhibitory influence upon the growth of fungal organisms (4, 5, 6). These studies further substantiate these findings; fungal activity was definitely retarded by 10% carbon dioxide concentrations and to a lesser extent by lower concentrations of the same gas and 2.5% oxygen. This inhibitory influence, however, appeared to lessen in the later stages of storage. Pure cultures of *Penicillium expansum* exposed to similar treatments were also

retarded in growth and sporulation was reduced. It was observed that the colonies subjected to 10% carbon dioxide for 9 days and then placed in air did not exhibit the rapid recovery that was shown by the colonies stored under low oxygen conditions. This continued growth retardation of the carbon-dioxide-treated colonies when removed to air may have been due to the acidification of the media or to the alkaline reaction of fungal hyphae as shown by Thornton (34).

The final stages of the senescent activities of fruit are characterized by physiological breakdown of the tissues, but a detached analysis of these activities is rendered extremely complex due to the inherent varietal reactions of fruits to environmental influences both before and after removal from the tree. The chemical studies on the physiology of apples by Archbold (1), also those of her colleagues, are invaluable contributions in this field of investigation.

It has been found in these studies that physiological breakdown of the apple is associated with marked increases in the respiratory activity, transpiration, permeability and the alkalinity of cells so affected. The accelerated loss of sugars, as seen with apples treated with low oxygen concentrations, did not appear to induce disorganization of the cells; indeed these fruits were shown to have relatively high osmotic pressures, percentage of total solids and moisture content. Furthermore, if it be assumed that the strength of the cells can be gauged by the amount of pressure required to break the same with a penetrometer, then these cells which were subjected to low concentrations of carbon dioxide and also oxygen are high in cell wall materials such as pectins and cellulose.

From the evidence obtained, it is apparent that the substrate for respiration must consist not only of the carbohydrates in the cell but also certain cell wall constituents, because in atmospheres in which there is a low rate of oxidation the disappearance of pectic materials is apparently retarded. Furthermore, it is thought that the supply of acid is not necessarily limited by the amount of sucrose present.

The increase in the permeability of carbon-dioxide-treated (2.5 and 5%) cells may possibly be attributed to the dilution of protoplasmic colloids, in view of the relatively high water content of these tissues; this is partially supported by the relatively high respiration rates of turgid fruits. The only explanation that can be offered for this increase in permeability, which is characteristic of physiological disturbances, is that it may be offset by the slow rate of oxidation under such conditions.

The breakdown occurring under the above conditions has been designated as "mealy breakdown" and is possibly due to the combined effect of low temperatures and carbon dioxide.

Excessive concentrations of carbon dioxide have been shown to induce the condition known as "brown heart" which is usually initiated in the core area of senescent fruits where the internal concentration of carbon dioxide is relatively high. This disease has been described in detail by Kidd and West (22).

Fruits which had been stored for a prolonged period at 3° C. were found to break down after exposure to 100% nitrogen at 21° C.; there was also a loss of red pigmentation in these apples. No such disturbances were noted, however, in the freshly picked apples under similar conditions.

It is possible, therefore, that these physiological responses in the senescent fruits were due to the run-down state of the enzymatic system and its consequent inability to withstand withdrawal of the oxygen supply.

The superficial scald on Golden Russet apples which appears very late in the storage season in carbon dioxide is difficult to explain. It may be that the extinction point (E) for these fruits is reached at the time of scald development and that some product of anaerobic fermentation, as, for example, acetaldehyde, proved toxic to the epidermal cells. Davis and Blair (8) recommend the use of oiled wraps for the prevention of scald in apples stored in artificial atmospheres.

In conclusion, we have seen that storage in carbon dioxide produces certain cellular changes typical of undesirable physiological conditions within the cell. It is believed, however, that the slow rate of oxidation of cell wall materials in low concentrations of carbon dioxide is of considerable importance in the longevity of the cell. Furthermore, the retardation of acid loss by carbon dioxide below a certain critical concentration is possibly responsible for a high degree of peptization being maintained in the protoplasmic colloids, a condition which prevents dehydration and final coagulation of the protoplasm.

SUMMARY

The influence of carbon dioxide and low oxygen concentration on the physiological activities of apple tissue has been studied.

It has been shown that low (6.2%) and high (53.5%) concentrations of carbon dioxide stimulate and depress respectively the total carbon dioxide output of fruits during a period of 5 days. Low concentrations of oxygen (1%) increased the output of carbon dioxide of apples; when these fruits were returned to air the rate of oxygen uptake was found to be lower than in those fruits stored continuously in air.

Fruits which had been stored in 5% and 10% carbon dioxide at 3.5° C. for several months and removed to 21° C. were observed to respire more rapidly than the controls stored in air.

Moisture loss and the size effect were noted. Golden Russet apples lost 3 times as much moisture as carbon dioxide by weight, and the loss of these constituents from fruits varied inversely as the size. In the fruits which were treated with carbon dioxide (2.5, 5 and 10%), over long periods there was found to be an increased hydrogen ion concentration in relation to the controls in air. A decrease in hydrogen ion concentration of apple and pear juice was observed in fruits stored in 100% carbon dioxide for one week and this was more marked at high temperatures; a slight increase was also seen with fruits kept in 100% nitrogen.

Carbohydrate loss appeared to be accelerated by carbon dioxide treatment, and an increased loss of sucrose in the low oxygen series was evident, but a definite retardation was noted in the loss of total solids in the expressed juice of fruit under the latter conditions as compared with the former.

Apple cells were found to be more permeable to apolar compounds than to polar, and carbon dioxide increased the permeability of cells to water, particularly at low temperatures, as measured plasmolytically. The electrical conductivity of leachings (electrolytes) from tissues immersed

in distilled water indicated that carbon dioxide increased the permeability of cells, but that low oxygen caused a decrease.

Fungal invasion was retarded by carbon dioxide and to a lesser extent by low oxygen. Colonies of *Penicillium expansum* were likewise retarded both in growth and sporulation.

Two types of physiological breakdown in Cox Orange apples were observed; namely, "brown heart," due to excessive carbon dioxide concentration (10%), and a condition similar to "mealy breakdown" in the 2.5 and 5% treatments. A type of breakdown and loss of pigmentation occurring in McIntosh and Stark apples stored in 100% nitrogen is described. Lastly, it was noted that Golden Russet apples developed superficial scald when stored for prolonged periods in carbon dioxide.

Finally, fruits affected with physiological disorders were found to have the following characteristics: (1) high rate of respiration, (2) high rate of moisture loss, (3) low acid content, (4) low total solids, (5) low osmotic pressures, and (6) increased permeability to water and electrolytes.

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BOOK REVIEWS

SNEDECOR, C. W.—STATISTICAL METHODS. Collegiate Press Inc., Ames, Iowa, U.S.A. Price $3.75.

Excerpts from the preface of this book summarize very neatly some of the author's objectives which, within the text, have been very adequately realized. "It is the novice to whose needs this book is directed. It is hoped that he may be furnished with a smoothly working combination of experimental data and statistical method. . . . . . It is a fundamental belief of the author that statistical method can be used competently by scientists not especially trained in mathematics. . . . . . Small sample methods are prerequisite in most biological data. For that reason, they are introduced at the start. The theory of large samples received scant attention. . . . . Fundamentally statistics is a mode of thought. Biometrics is a delineation of living things."

In view of the many recent developments in the field of statistics applied to experimental biology, it is encouraging to find an author who not only refuses to be deluged by the frequency and apparent complexity of these developments, but calmly and very effectively reduces them to a very few simple principles. The mistake is not made of treating recent ideas as necessarily belonging to a more advanced stage of development. Wherein these ideas cut across and are in advance of the old ones, the latter are either relegated to an inferior position, or are discarded entirely. The classical theory of large samples is regarded for the first time in an elementary text as a special case of the more complete theory which deals with samples of all sizes. The correlation coefficient is no longer regarded as the statistician's idol. Its limitations are clearly pointed out and the discussion of it relegated to a position inferior to that of the more substantial linear regression coefficient. The approach to the theory of linear regression is one of the neatest that has yet appeared in any statistical text.

As would be expected in a modern text, the analyses of variance and covariance occupy a prominent position, and throughout the discussion of these topics, the intimate relation between statistical ideas and experimental design, is emphasized. The analyses of variance and covariance are introduced, not as a new and distinct phase of the statistical method, but as an integral part of the whole. This is as it should be; and thus we find the term variance referred to at the very beginning of the discussion of tests of significance, and the correlation coefficient is defined at once as the ratio of covariance to the geometric mean of the variances of the variates being correlated. In this way the student is fully prepared for the discussions that follow.

Two excellent chapters discuss experiments with attributes and enumeration data. These will be found very helpful to those who have had difficulty in following through the reasoning in various applications of the Chi-square tests.

A chapter on individual degrees of freedom lays the foundation for the understanding of the discussions in more advanced texts and papers, of the principles of confounding in experimental design. This chapter follows

very logically after a discussion of methods of fitting curved regression lines, with particular emphasis on the method of orthogonal polynomials.

Taken as a whole this book is a very fine effort. While elementary in tone and exposition, it covers a wide field, and will be found of great value not only to teachers of modern methods, but to those who are endeavouring to learn, and to apply these methods to their everyday research problems in biological science.

—C. H. Goulden.

Imperial Bureau for Herbage Plants.

The Imperial Bureau for Herbage Plants, Aberystwyth, Great Britain, has recently published three very excellent bulletins on the subject of forage crops seed production.

Bulletin No. 22, *Technique of Grass Seed Production at the Welsh Plant Breeding Station*, presents a complete and comprehensive description of the methods employed by the Aberystwyth station in the work of seed production from bred strains. The very adequate manner in which all the various stages in the program of developing these strains is outlined will be of much interest and assistance to all engaged in work of a similar nature, irrespective of the place or conditions in which such work is being done. All who are working with grasses will find benefit in a study of its pages. The sections on field management and harvesting are of equal interest and importance to that which describes the methods followed in isolating the strains for seed production.

Bulletin No. 23, *Production of Legume Seed*, is a collection of concise, informative articles describing practical seed production methods for important legume crops in ten different countries. The articles are prepared by leaders in the field of work in each of the countries, and such important crops as, alfalfa, red clover, alsike clover, white clover, etc., are dealt with.

Bulletin No. 24, *Collection of Native Grass Seed in the Great Plains, U.S.A.*, outlines the general program of work now going on in the United States in connection with soil conservation and regrassing in the Great Plains area. Recognition is given to the value of the native grasses for this purpose, and methods of harvesting seed of the more important species are described. The need for assistance from plant breeders in selecting improved strains of these species is emphasized. The bulletin is of special interest to those in Canada who are now engaged in regrassing schemes in the Prairie Provinces.

—F. Dimmock.